ransactions

RICAN FOUNDRYMEN'S ASSOCIATION

DECEMBER
1944

Issued Four Times Per Year

TRANSACTIONS

AMERICAN FOUNDRYMEN'S ASSOCIATION
INCORPORATED

Published and copyrighted by the American Foundrymen's Association, Inc.
222 West Adams Street, Chicago 6, Illinois

Entered as second class matter September 9, 1938, at the postoffice at Chicago, Illinois, under the Act of March 3, 1879.

Issued Quarterly

Subscription Price†:
Members:
$4.00 per year; $1.00 per copy

Subscription Price:
Non-Members:
$15.00 per year; $4.00 per

VOL. 52 DECEMBER, 1944 No

A.F.A. Organization and Personnel—1944-45

Officers and Staff

**President,* R. J. Teetor, Cadillac Malleable Iron Co., Cadillac, Mich.

**Vice President,* Fred J. Walls, International Nickel Co., Detroit.

Secretary, R. E. Kennedy[1].

Treasurer, C. E. Hoyt[1].

Assistant Treasurer, J. Reininga[1].

Director, Technical Development Progr
N. F. Hindle[1].

Business Manager, W. W. Maloney[1].

Board of Directors

Terms Expire 1945

J. E. Crown, U. S. Navy Yard, Washington, D. C.

H. S. Simpson, National Engineering Co., Chicago.

*I. R. Wagner, Electric Steel Castings Co., Indianapolis, Ind.

*S. V. Wood, Minneapolis Electric S Castings Co., Minneapolis.

W. L. Woody, National Malleable & S Castings Co., Cleveland.

Terms Expire 1946

D. P. Forbes, Gunite Foundries Corp., Rockford, Ill.

Roy M. Jacobs, Standard Brass Works, Milwaukee, Wis.

Max Kuniansky, Lynchburg Foundry Co., Lynchburg, Va.

Harry Reitinger, Emerson Engineers, York.

*Wm. B. Wallis, Pittsburgh Lectro Furnace Corp., Pittsburgh.

Terms Expire 1947

Frank J. Dost, Sterling Foundry Co., Wellington, Ohio.

S. D. Russell, Phoenix Iron Works, Oakland, Calif.

R. T. Rycroft, Jewell Alloy & Malleable Co., Inc., Buffalo.

*L. C. Wilson, Reading Steel Casting American Chain & Cable Co., Reading, Pa.

Joseph Sully, Sully Brass Foundry, Toronto, Ont.

---

* Member of Executive Committee.
[1] Association Office, 222 West Adams St., Chicago 6, Ill.
† In accordance with Article III, Section 3, By-Laws.

Centrifugal Castings

By Peter Blackwood* and John Perkins*, Windsor, Ontario, Canada

Abstract

The practice of centrifugal casting is by no means new. At the break of the century symmetrical shapes, such as flywheels and locomotive wheels, were being spun on a center pour basis. Cast iron pipe has been manufactured centrifugally for a number of years. The types of centrifugal castings have been briefly classified into three groups: (1) Die molds, (2) semi-centrifugal—center pour, (3) True centrifugal—cylindrical shapes, the inside diameter of which is governed by the volume of metal poured. In the foundry with which the authors are connected, they have been classified into the following groups: (1) Dry sand spinning, (2) die mold spinning, (3) green sand spinning. The following paper is based on these three types.

Dry Sand Spinning

1. At the outbreak of the war, forging hammers were at a premium. The steel casting foundries were called upon to fill the breach. We, as an automobile company, immediately started to produce army vehicles and, due to the lack of forging facilities, a great number of forgings were converted to castings. In Fig. 1 is shown a steering end ball socket. At the right is the statically cast socket weighing 75 lb. On the left is the final die spun job weighing 36 lb.

Molding and Pouring

2. This job evolved from the static casting to a dry sand spinner. This consisted of two kidney-shaped flasks representing the cope and drag, which were rammed up with green sand and baked. They were then sprayed, while hot, with silica wash. After being assembled they were put into adaptors and the molten metal poured into the spinning mold. It soon became apparent that this method was not the most economical way of making this casting, so the permanent die mold was developed, which will be explained later.

*Foundry Supt. and Asst. Foundry Supt. of Ford Motor Co. of Canada, Ltd.

Note: This paper was presented at a Centrifugal Casting Symposium Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 28, 1944.

FIG. 1—LEFT—STEERING END BALL SOCKET SPUN IN A PERMANENT MOLD, YIELD 74 PER CENT. RIGHT—THE SAME PART CAST STATICALLY, YIELD 33 PER CENT.

3. Another critical job was the universal carrier sprocket shown in Fig. 2. Originally this sprocket had been cut from plate steel and the teeth flame hardened. This was a slow procedure and our production was greatly impaired. A pattern was made specifically to spin the job (Fig. 3). We started, experimentally, first spinning one, then three, five, and finally, thirteen, equipment alone limiting the number. Note bleeder at the tip of every tooth to make sure that all the gas is taken away. Figure 4 shows the bottom plate and the drag core. All other drags in this cluster have the runners out. Likewise, the top cope core has no feeder risers. These cores are stacked as shown in Fig. 5. Twenty-six biscuit cores comprise the cluster. Next, the pouring cup and top plate are adjusted and the assembly bolted down, as shown in Fig. 6. Figure 7 shows the assembly in the spinning adapter, which is driven by a 5 hp. motor attached to the cut down axle of a truck rear end and the adapter bolted to a plate fixed to the cut down drive shaft.

5. The motor is started, spinning at a set speed of 167 rpm., and the metal poured in at a temperature of 2830 °F., the most natural packing condition we have found in all our research. The cluster is allowed to spin 3 min. after the pouring is finished. Figure 8 illustrates the pouring operation. It can be seen readily that the metal is not forced into the mold. The weights of mold, metal and castings are as follow:

Total weight of assembly ready to pour, lb.......	865
Total weight of metal poured, lb.................	443
Total weight of metal and assembly, lb..........	1308
Weight of cleaned cluster, lb....................	443
Weight of 13 sprockets at 22 lb. each...........	273
Yield, per cent..................................	65

Time elapsed from start to finish of pour—1 min. 5 sec. Figure 9 shows the shake-out operations. Note arbor reinforcing the dry sand cores.

Core Sand

6. In this foundry, we have endeavored to standardize our coremaking operations as much as possible. Two types of sand are used, the properties of which are shown in Table 1. Figure 10 shows the shape of these sand grains.

Core Sand Mixture

7. The core sand mixture used is as follows:

Bank Sand, lb.	200
Sharp Sand, lb.	800
Cereal Binder*, qt.	17.5
Linseed-base core oil*, qt.	5.6

The physical properties of this core sand mixture are shown in Table 2. The compression test on a 2-in. diam. sample runs from 2500 to 3000 lb. All of the test samples are prepared according to A.F.A. standard methods of testing.

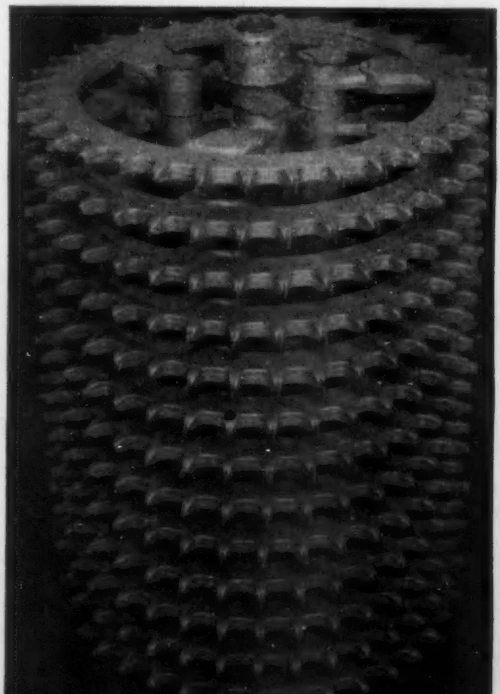


FIG. 2—UNIVERSAL CARRIER SPROCKET CENTRIFUGALLY CAST TO SIZE, YIELD 65 PER CENT. NOTE BLEEDER AT TIP OF TEETH FOR GAS ESCAPE.

*Trade names of the products used may be obtained from the authors.

FIG. 3—DRAG PATTERN FOR SPROCKET CASTING WITH RUNNER GATES REMOVED. ALL DRAG CORES EXCEPT BOTTOM ONE ARE MADE FROM THIS PATTERN.

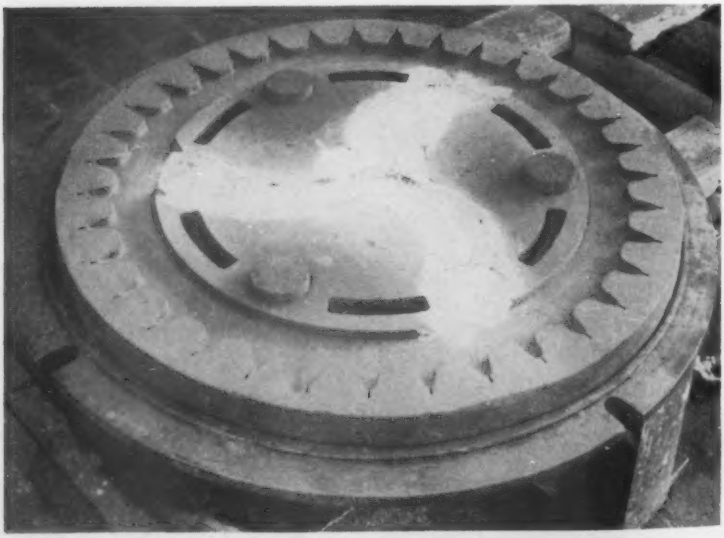


FIG. 4—BOTTOM DRAG CORE FOR SPROCKET CASTING. NOTE RUNNER GATES THROUGH WHICH ALL METAL PASSES.

Table 1

CORE SAND PROPERTIES

Passing Mesh no.	*Bank Sand, Per Cent*	*Sharp Sand, Per Cent*
20	0.06	0.8
40	0.8	7.5
70	9.2	82.85
100	30.0	9.0
140	35.0	0.3
200	4.5	0.15
270	17.5	0.10
Pan	2.5	0.10
A.F.A. Fineness no.	166	42
Chemical Analysis		
Ignition loss	0.72	0.46
Silicon dioxide	91.3	94.4
Iron oxide	0.86	0.23
Aluminum oxide	2.74	1.75
Titanium oxide	0.20	0.13
Zirconium oxide	0.14	0.05
Calcium oxide	0.40	0.70
Magnesium oxide	0.10	0.00
Alkalis	0.85	0.59
Carbon dioxide	0.70	0.40
Rational Analysis		
Quartz	81.5	87.7
Feldspar	15.0	10.3
Clay	3.5	2.0

FIG. 5—A STAGE IN THE ASSEMBLY OF ALTERNATE DRAG AND COPE CORES FOR THE SPROCKET CASTINGS.

8. The cores are sprayed in the green state with the mixture shown in Table 3. This mixture has a specific gravity of 35 to 40 °Bé. The bentonite paste is mixed separately, and both mixtures are kept agitated in the tanks.

FIG. 6—NINE SPROCKET DRAG AND COPE CORE ASSEMBLY WITH POURING CUP AND TOP PLATE ADJUSTED. JACKET HAS BEEN OUTGROWN. PRESENT PRACTICE DISCARDS JACKET ENTIRELY.

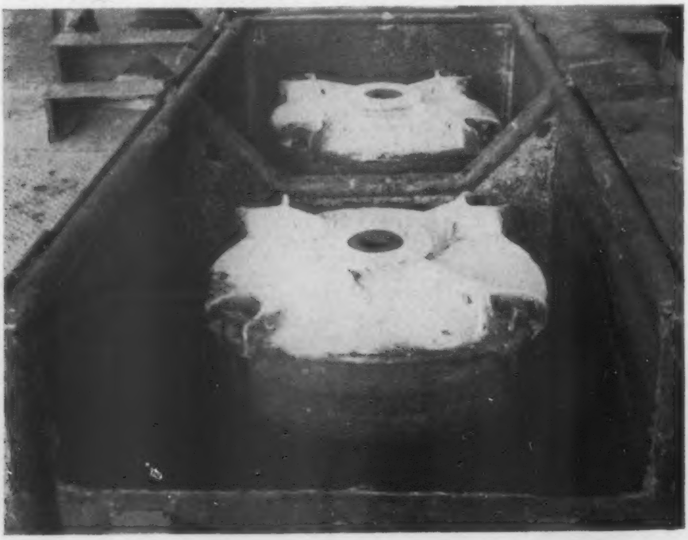


FIG. 7—SPROCKET ASSEMBLY IN THE SPINNER ADAPTER POT.

Table 2

PHYSICAL PROPERTIES OF CORE SAND MIXTURE

Moisture content, per cent	2.8
Green permeability	112
Green bond strength, psi.	2.6
Dry permeability	287
Dry tensile strength, psi.	350

Table 3

CORE SPRAY MIXTURE

Water, gal.†	48
Silica flour, lb.	200
*Bentonite paste, gal.	12
Glutrin, qt.	4.8
****Bentonite Paste***	
Bentonite, qt.	19.2
Water (180 °F.), gal.	36

9. The cores are baked in a vertical oven. They are baked slowly, taking 30 min. to reach the baking zone, 20 min. baking at 560 °F. and 35 min. coming down to the unloading station.

10. Inasmuch as the cores are sprayed green, there is very little cleaning required before assembling.

11. The castings are cut from the cluster by a torch. The inside diameter is ground even and a slight grinding operation "touches up" the teeth.

FIG. 8—POURING CENTRIFUGALLY CAST SPROCKET. NOTE THAT METAL IS NOT FORCED INTO MOLD.

†British measures have been converted to United States measures throughout the paper.

FIG. 9—SPROCKET CASTING SHAKE-OUT.

HEAT TREATMENT

12. The castings are hardened at 1500 °F. (½-hr. up to heat and ½-hr. soak). The sprocket is then quenched in an 8 per cent caustic solution, using a hydraulic press which hardens the teeth and leaves 1¼-in. on the inside diameter comparatively soft for machining.
The casting is then drawn at 850 °F. for ¾-hr. A typical Brinell hardness on the teeth will run about 385, while 1¼-in. of the inside diameter is 229.

13. The structure of the wearing part of the sprocket is sorbite, tapering off to pearlite in the machined parts. The only machining necessary is the drilling of 18 holes and a cut off the inside diameter. Figure 11 shows a radiograph of a section of our current production, one of which is checked every day by the x-ray.

14. Some idea of the savings effected by using the centrifugal method of casting these sprockets can be gained from the following figures:

Estimated annual saving of original material, lb. 8,860,000.
Estimated annual saving of labor, hr. 725,000.
Annual savings on labor and material, $1,720,000.00.

Cluster Castings

15. Another very interesting job, patterned along lines similar to the sprocket, is the bearing shown in Fig. 12. This was originally a forging. A one-inch hole had to be drilled down the center and the shaft part had to be tapered. In the casting form, the hole is cast to size, the taper also, and the

only machining necessary is on the ball. One hundred forty-four pieces are cast in one cluster, with a yield of 91 per cent. Shown in Fig. 13 is the cope core. Figure 14 shows a section of the cope and drag with center core set in left half. Figure 15 shows a section emphasizing the "umbrella gate." The "umbrella gate" was devised to increase the yield on the cluster type of castings. It insures against the molten metal being spattered out from the center sprue into the ingate and from there to the casting proper before the body of metal reaches each respective layer of cores.

16. Figure 16 shows a washer for the universal carrier bogie assembly, which was formerly machined from round steel stock. There are 192 castings on this cluster, with a yield of 85 per cent. The only machining required is a reaming operation on the hole and a slight facing operation.

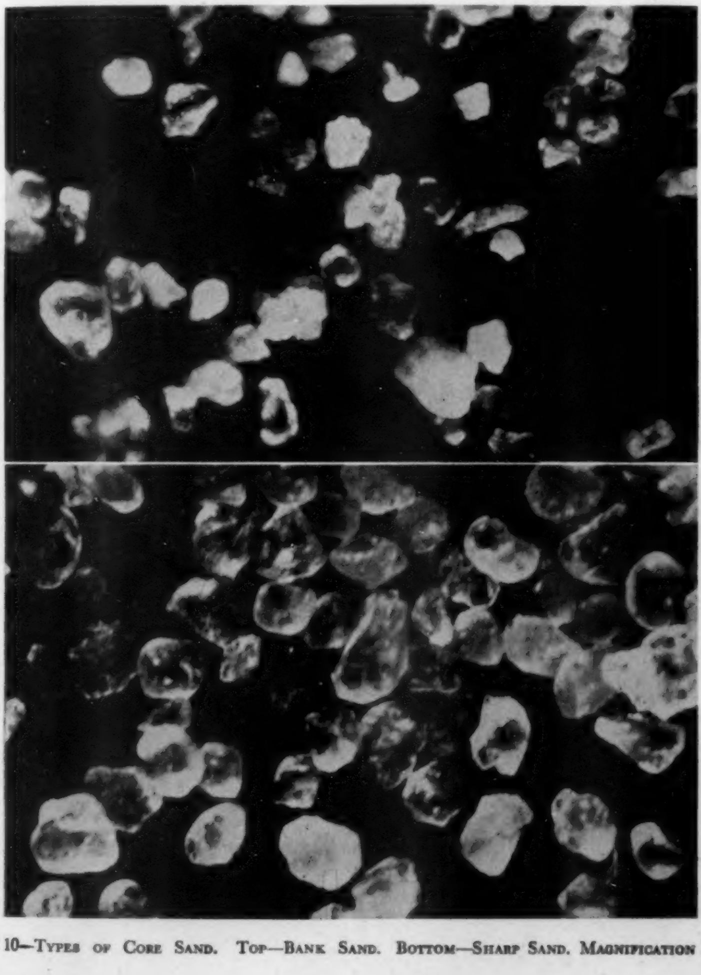


FIG. 10—TYPES OF CORE SAND. TOP—BANK SAND. BOTTOM—SHARP SAND. MAGNIFICATION X25.

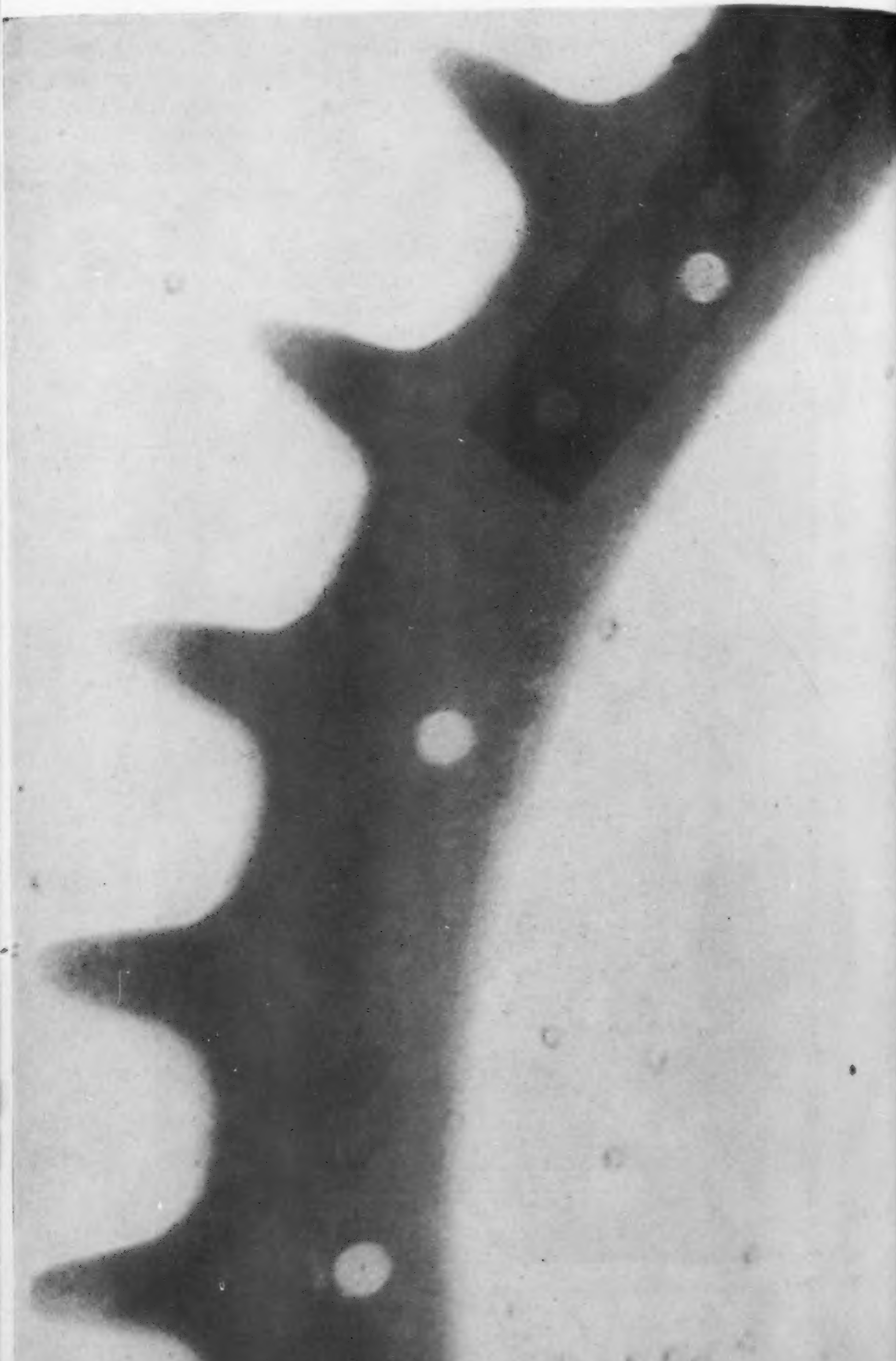


FIG. 11—AT LEFT—RADIOGRAPH OF A SECTION OF CENTRIFUGALLY CAST CARRIER SPROCKET.

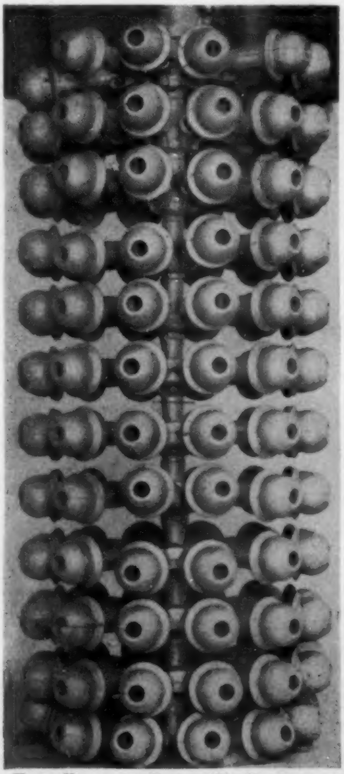


FIG. 12—A TRUE "CHRISTMAS TREE FORMATION" OF 144 CENTRIFUGALLY CAST BEARINGS. YIELD 91 PER CENT.

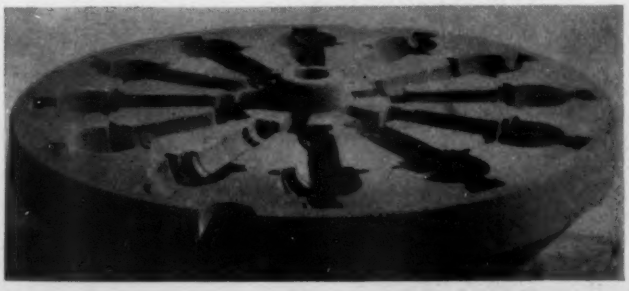


FIG. 13—ONE OF THE 24 COPE CORES IN BEARING ASSEMBLY (FIG. 12).

17. Figure 17 shows a cluster of cross shaft block castings. These blocks, like the washer, formerly were machined from bar stock. The saving in man hours in the machine shop more than pays for the extra cost of dry sand cores. Another point is the conservation of metal in the cluster pouring of this casting.

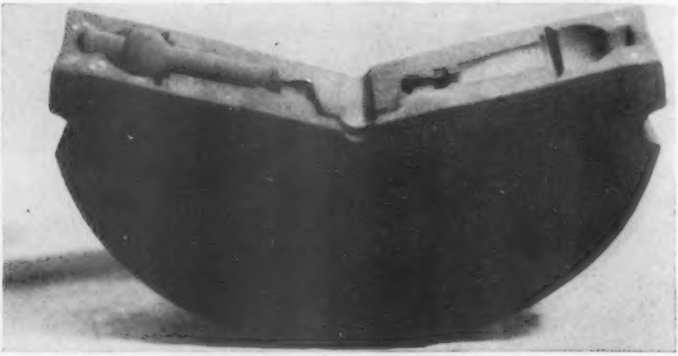


FIG. 14—A SECTIONAL VIEW OF A BEARING CASTING COPE AND DRAG WITH A CENTER CORE SET AT LEFT.

FIG. 15—A SECTIONAL VIEW OF BEARING CASTING CORE EMPHASIZING THE "UMBRELLA GATE."

18. Figure 18 shows still another of our production jobs in the cluster form of dry spinning. This illustrates quite clearly that it is not necessary to feed from the center of a round casting. These round castings are all gated from the side. It will be noticed, however, that in this type of work the feed is ahead of the casting. Bearing in mind that we spin anti-clockwise, it can be seen that the metal is whipped into the mold cavity by the centrifugal action.

19. Figures 19, 20 and 21 show types of castings with which we experimented during a very critical period of metal shortage. These castings show the varied applications of the centrifugal principle. Figure 19 shows an aeroplane propeller hub. On the left is the original 280-lb. forging. On the right is the finished machined product. The center shows a sectional view of the casting we produced. As many cores as possible were used and, by means of gating it at the top and spinning, we were able to produce a good, solid casting weighing 60 lb. Figure 20 shows a cluster of brake shoe castings which enabled us to maintain production of our army vehicles when we were unable to obtain the fabricated type of brake shoes.

20. At one time, the non-ferrous metals were so scarce in Canada that it was seriously considered turning to steel for propellers. It was with this thought in mind that the cluster shown in Fig. 21 was developed. This shape of casting lends itself ideally to spinning. Figure 22 shows a section of this propeller casting illustrating the good, solid metal right out to the tip.

21. Following along the umbrella gating lines, a cluster was laid out to produce forty-eight 3-in. 10-lb. mortar bombs, six layers of eight. Figure 23 shows this cluster. The bomb is cast to size and the only machining required is the threading of both ends and the band finishing. The center core is set in a good-sized core print on the outside of the core. A good, solid core print is necessary to insure against any shift of the center core when the centrifugally forced metal strikes it.

22. Apparently there is no limit to what can be spun in dry sand cores. Figure 24 shows a sample of our future development when the pressure of wartime ends and allows us to turn to peacetime production. There seems no doubt that, by observing a few simple rules, such as maintaining a rigid control on temperature in conjunction with a constant speed, many kinds of unsymmetrical arrangements of castings can be produced commercially. The question has been asked, "Is it cheaper to spin a part or cast it statically?" Our experience has been that the yield, together with the saving in machining

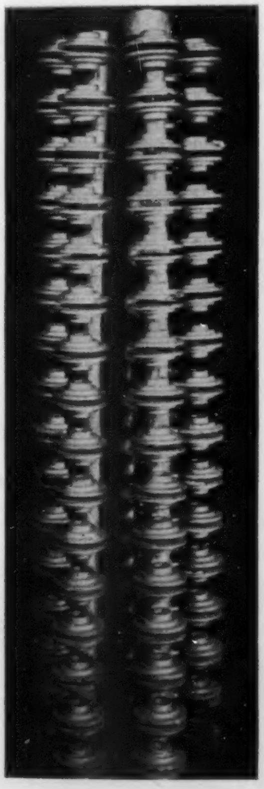


FIG. 16—(LEFT) A CENTRIFUGALLY CAST CLUSTER OF BOGIE WASHERS. YIELD 85 PER CENT.
FIG. 17—(RIGHT) A CENTRIFUGALLY CAST CLUSTER OF CROSS-SHAFT BLOCKS. THE ARRANGEMENT PERMITS ECONOMIZING ON CORE SAND. YIELD 90 PER CENT.

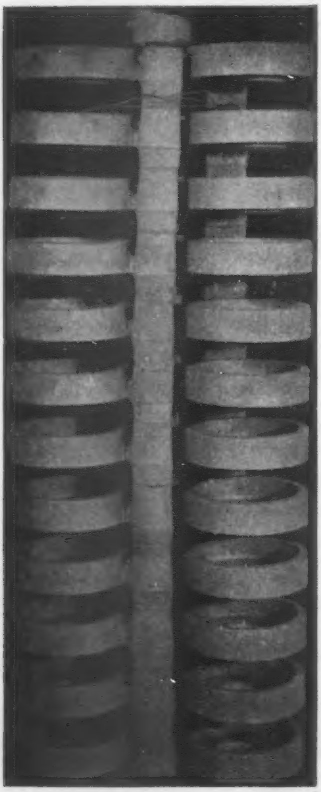


FIG. 18—A CENTRIFUGALLY CAST CLUSTER OF ENGINE COVERS. NOTE THREE ROUND CASTINGS IN EACH LAYER SPUN FROM A CENTRAL AXIS INSTEAD OF THE MORE COMMON PRACTICE OF SPINNING A ROUND CASTING ABOUT ITS OWN AXIS.

FIG. 19—LEFT—ORIGINAL 280-LB. AEROPLANE PROPELLER HUB FORGING. CENTER—SECTIONAL VIEW OF THE 60-LB. SPUN CASTING. RIGHT — FINISHED MACHINED CASTING.

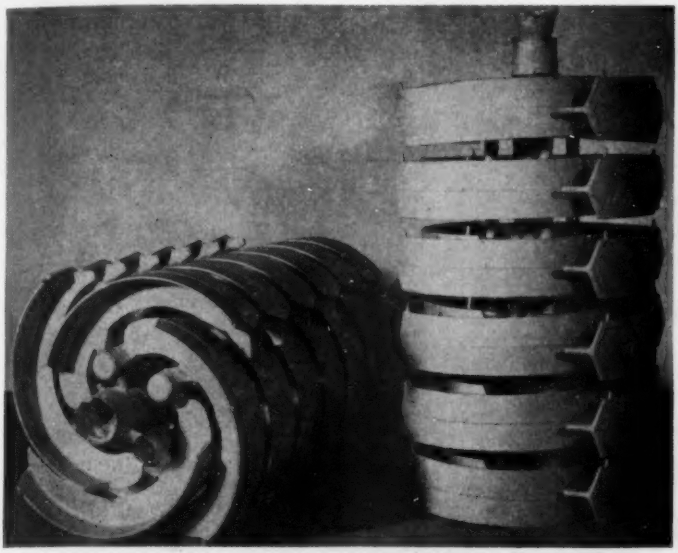


FIG. 20—CENTRIFUGALLY CAST CLUSTERS OF BRAKE SHOES, YIELD 65 PER CENT.

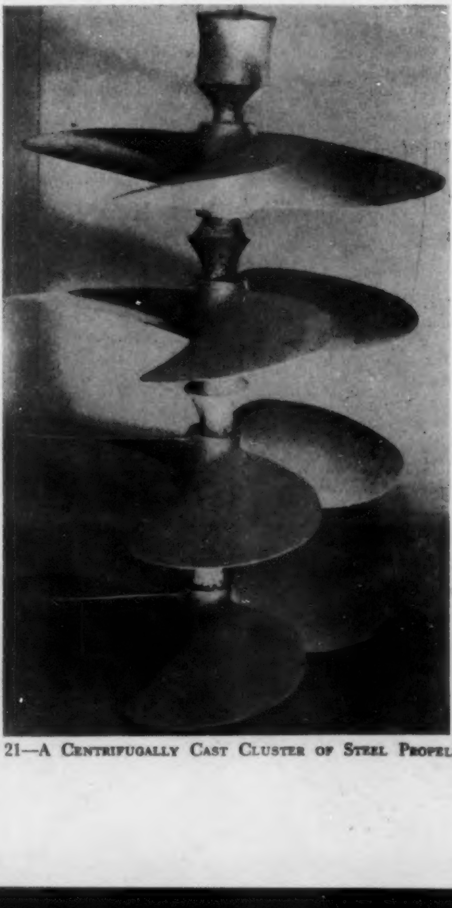


FIG. 21—A CENTRIFUGALLY CAST CLUSTER OF STEEL PROPELLERS.

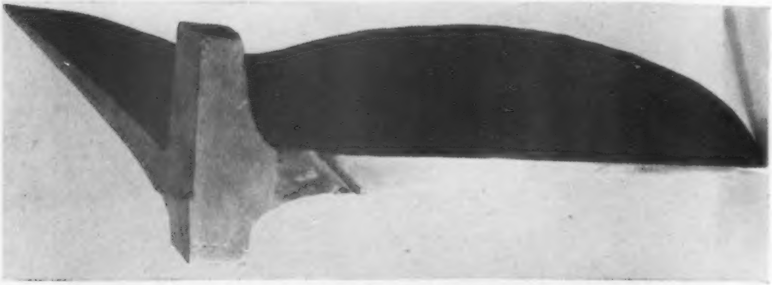


FIG. 22—A SECTIONAL VIEW OF THE CENTRIFUGALLY CAST STEEL PROPELLERS SHOWN IN FIG. 21.

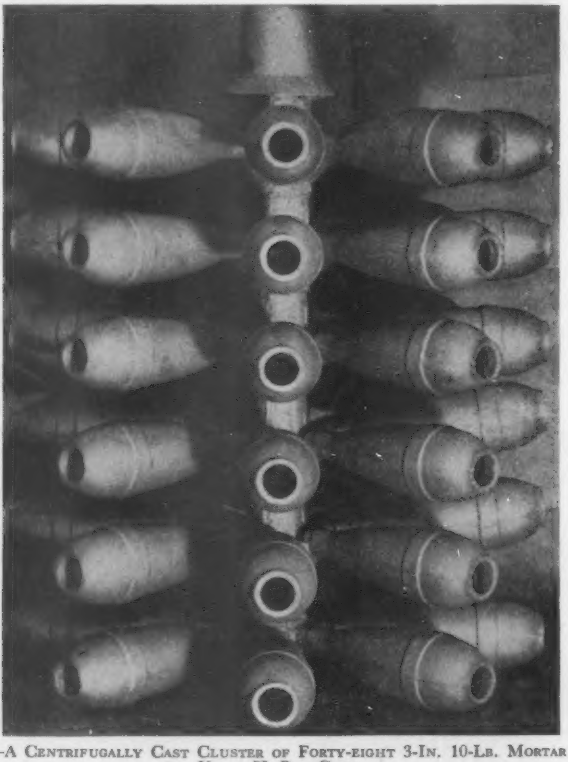


FIG. 23—A CENTRIFUGALLY CAST CLUSTER OF FORTY-EIGHT 3-IN. 10-LB. MORTAR BOMBS. YIELD 75 PER CENT.

due to being able to hold the casting closer to finished specifications, makes the centrifugal method more economical than the static method of casting.

DIE MOLD SPINNING

23. Cost is always an important factor in the selection of methods to produce castings. As previously stated, we were spinning single castings, as shown in Fig. 1, in dry sand molds, but the saving in metal was being consumed in the cost of processing the sand.

Permanent Mold Die Design

24. A permanent die mold was the logical solution to this problem, but we wanted a method whereby long life and a cheaply manufactured die could be combined. Our first trials proved to us conclusively that some method had to be devised to absorb the force of the molten metal as it first strikes the die. A recess was cut in the die and a core inserted. Figure 25 shows this permanent mold set up. The die is split in half with one locator pin and bushing in each half. Grooves for locating the cores can be seen in the die on the left of Fig. 25, while on the right the half splash and center core are located in place. It can readily be seen how the metal enters through the gate (A), hits the splash core and fills the die cavity. Adopting this principle, we have dies in service that have produced over 6000 castings.

25. Not only did the splash core prolong the life of the die, but it enabled us to cast these dies in our cast iron department from regular brake drum iron of the following analysis:

	Per Cent
Carbon	3.10 to 3.30
Manganese	.60 to .80
Silicon	2.10 to 2.20
Sulphur	.10 (max.)
Phosphorus	.10 (max.)

26. Thus we were able to depart from the more costly practice of using high alloy materials. Figure 26 shows the core boxes and pattern used to make the casting almost to size. A little grinding operation on the inside and

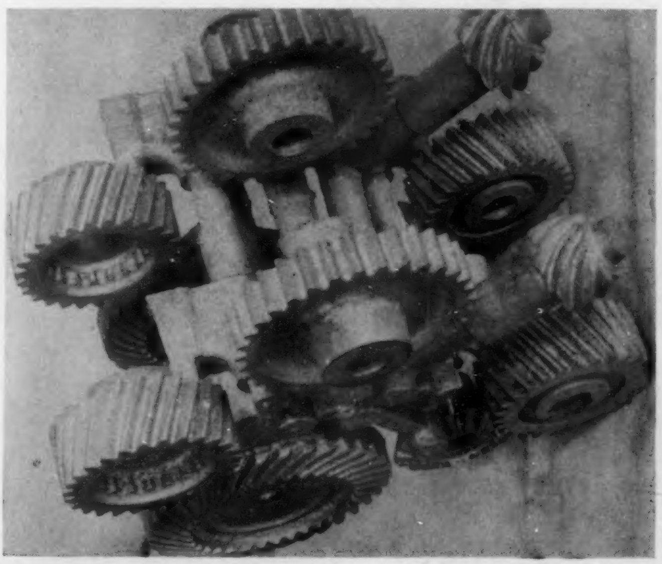


FIG. 24—AN EXPERIMENTAL CENTRIFUGALLY CAST CLUSTER OF GEARS FOR POST-WAR DEVELOPMENT

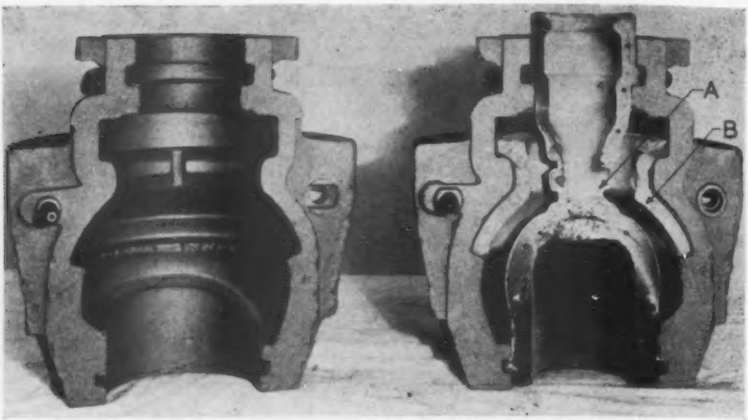


FIG. 25—THE TWO HALVES OF A PERMANENT DIE MOLD. THE HALF SPLASH CORE AND HALF CENTER CORE ARE SHOWN SET IN ON THE RIGHT. A—GATE ENTRANCE. B—SPLASH CORE.

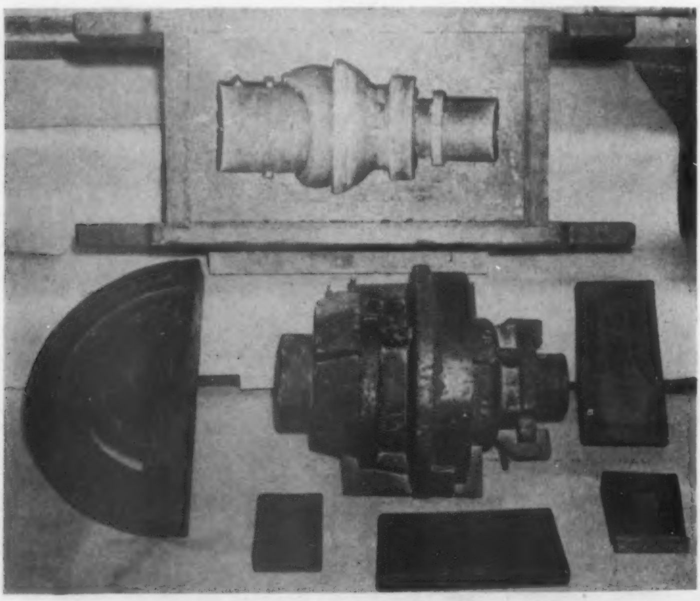


FIG. 26—PATTERN AND CORE-BOX EQUIPMENT FOR CASTING PERMANENT DIE MOLDS IN THIS FOUNDRY.

fitting in of the locator pins and bushings is all the machine work necessary. The total cost of the complete die is $46.00.

Gating

27. The location of the gate (A), Fig. 25, caused us a considerable amount of worry. We first cut in at the flange with a single gate. The casting was solid enough, but hot tears developed in the neck at the base of the ball section. A double gate was tried on the flange, with no better results.

Finally, a single gate was dropped right into the critical part of the neck and the crack disappeared.

Operation

28. In order to speed production of the castings from these permanent die molds, a special line was designed, the layout of which is shown in Fig. 27. In Fig. 28, a core setter is shown at work on the dies traveling along the slat conveyor. It will be noticed that the dies, although resting on the conveyor, are still hooked to their individual hangers and remain so throughout the entire operation, except when transferred to the pouring turntable. Figure 29 illustrates this more clearly as the closed-up dies follow along to the spinner turntable. The catch arrangements prevent the dies from shifting apart until they are located in the spinner pots. The slat conveyor, the overhead conveyor and the turntable are all synchronized so that there is always a spinner pot waiting for a die (Fig. 30).

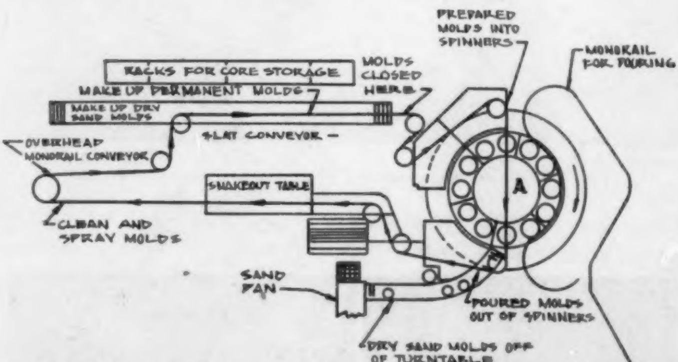


FIG. 27—GENERAL LAYOUT OF VERTICAL PERMANENT MOLD SPINNING UNIT. "A" TURNTABLE.

FIG. 28—CORE SETTING OPERATION FOR PERMANENT DIE MOLDS.

FIG. 29—GENERAL VIEW OF THE OVERHEAD AND SLAT CONVEYOR.

FIG. 30—TRANSFERRING THE PERMANENT DIE MOLD FROM THE OVERHEAD CONVEYOR TO THE SPINNING POT.

29. The turntable consists of 12 stations, or spinner pots. As soon as the pot with its die reaches the pouring station, it starts to spin anti-clockwise at our standard speed of 167 rpm. The pourer stands on the revolving table and pours the die (Fig. 31). The fact that the pourer stands still gives him a steadier pour and cuts down splashing of the metal. The pouring of this job, like that of all of our centrifugal castings with the exception of the aeroplane cylinder barrel, is "gentle." No effort is made to force the metal into the die other than that of the natural centrifugal action. As soon as the metal hits the die it chills, and it is quite interesting to note that even short-poured castings (cut up for inspection) produce a solid job. However, the extra metal is maintained as a margin of safety.

30. As the spinner pot passes out of the pouring zone the spinning stops, and the die is transferred back to the overhead conveyor and on to the shake-out, where the castings are removed from 3 to 5 min. after pouring. Figure 32 shows the shake-out. The catch has been snapped open allowing ample room to remove the casting from the die.

31. As the dies pass from the shake-out they are sprayed with silica wash (Table 3) on the parts which come in contact with the metal, and continue around to the assembly table. There are 49 dies to the line. Normal production on this line is 200 castings per hr. We carry five different types of castings, the steering end ball socket, large and small steering knuckle, short axle shaft and gear box housing. Figure 33 shows the steering knuckle. This casting is more irregular in design and yet lends itself very well to spinning in a permanent die mold.

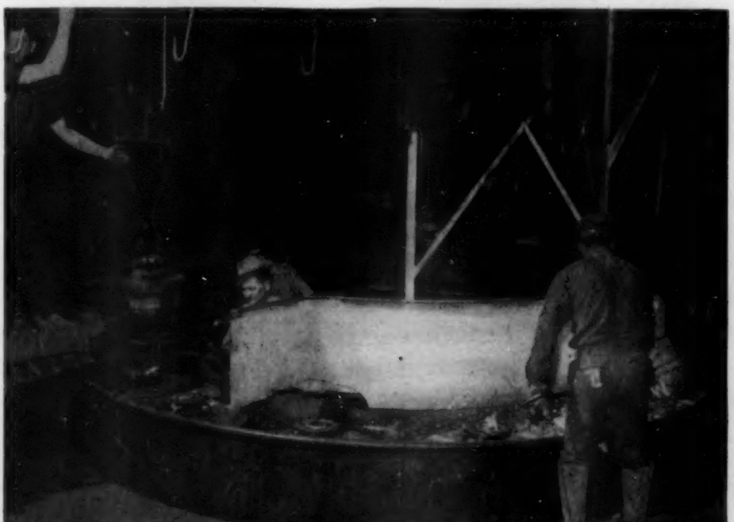
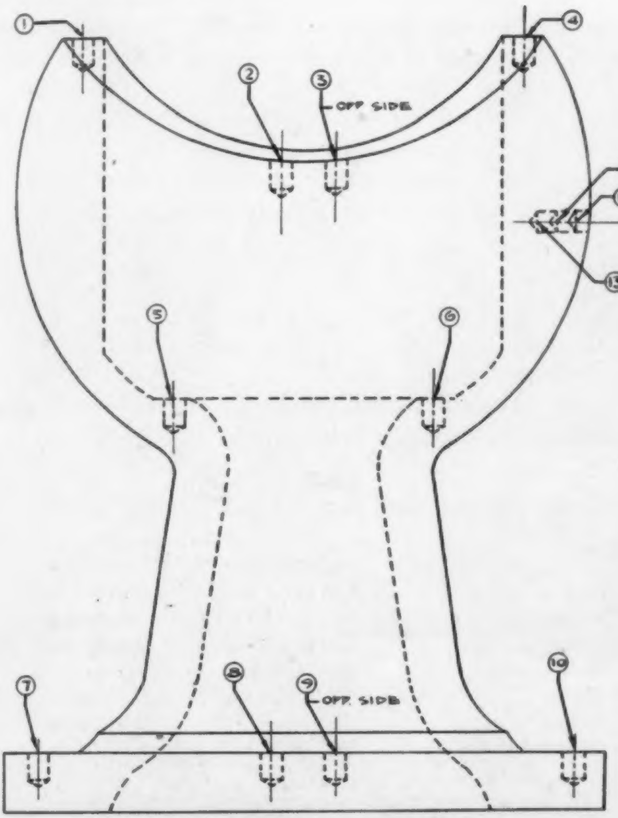


FIG. 31—THE REVOLVING TURNTABLE ON WHICH THE SPINNING DIES ARE POURED.

32. The question has been asked on numerous occasions whether the centrifugal action has any effect on separating the elements that make up the steel. With this thought in mind, 13 samples were taken from a centrifugally cast sample, from the locations shown in Fig. 34. The samples were analyzed for carbon, manganese and silicon in two different laboratories, and a definite uniformity of composition was established.

FIG. 32—SHAKE-OUT OPERATION. THE CASTING IS REMOVED FROM THE DIE BY LEVERAGE FROM THE BOTTOM OF THE CASTING.

FIG. 33—STEERING KNUCKLE CASTING SPUN IN A PERMANENT DIE MOLD. YIELD 85 PER CENT.



LEGEND	1	2	3	4	5	6	7	8	9	10	11	12	13
CARBON	.39	.38	.39	.38	.38	.38	.39	.37	.39	.39	.39	.39	.38
MANGANESE	.68	.66	.67	.68	.66	.68	.70	.68	.62	.67	.64	.70	.70
SILICON	.30	.30	.32	.31	.29	.30	.32	.31	.31	.32	.30	.31	.32

C11Q 3370-71
C11BQ

Fig. 34—Diagram Showing Location of Samples Taken for Analysis to Determine Effects of Centrifugal Action on Separation of Elements in Steel Casting.

Vertical Spinning

33. Another form of die spinning is the aeroplane cylinder barrel shown in Fig. 35. The most difficult part of this job is the heavy section from which the cooling fins are machined. We started spinning this casting on a horizontal axis with a grooved die (Fig. 36) to facilitate cooling of the heavy section. It soon became apparent that the speed we desired to pack the metal to meet the rigid magnaflux specifications could not be attained on a horizontal axis. If the speed was increased above 750 rpm., the tendency was to crack the casting. A number of experiments conducted on a temporary vertical spinner convinced us that spinning vertically was the ideal condition. A machine (Fig. 37) was designed and we have been producing this casting by vertical spinning for the past 8 months with exceptionally good results.

34. Figure 37 shows the mechanical details of the spinner unit. Figure 38 shows the die in relation to the casting, with end plug and core.

Melting and Pouring

35. The rigidly followed procedure in aeroplane cylinder production is described in the following paragraphs.

36. A select grade of scrap metal is melted down in a 500-lb. acid-lined electric furnace, and has the following approximate analysis:

	Per Cent
Carbon	0.35
Manganese	0.40
Silicon	0.20
Sulphur	0.03
Phosphorus	0.03

The metal is then "doctored" to conform with SAE 4140 specifications, which are usually kept on the low side (Table 4).

Table 4

SPECIFICATIONS FOR AEROPLANE CYLINDER METAL

	Per Cent	
	As Specified	*Desired*
Carbon	0.35 to 0.45	0.40 to.0.44
Manganese	0.60 to 0.80	0.60 to 0.80
Chromium	0.80 to 1.00	0.90 to 1.00
Molybdenum	0.20 to 0.25	0.20 to 0.25
Silicon	0.30 (max.)	0.30 (max.)
Sulphur	0.05 (max.)	0.03 (max.)
Phosphorus	0.05 (max.)	0.03 (max.)

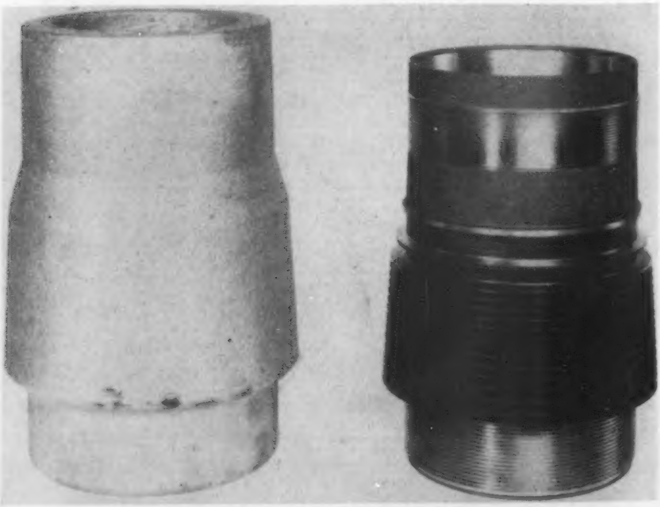


FIG. 35—A CENTRIFUGAL, VERTICALLY CAST AEROPLANE CYLINDER BARREL. LEFT—"AS CAST." RIGHT—THE FINISHED PRODUCT.

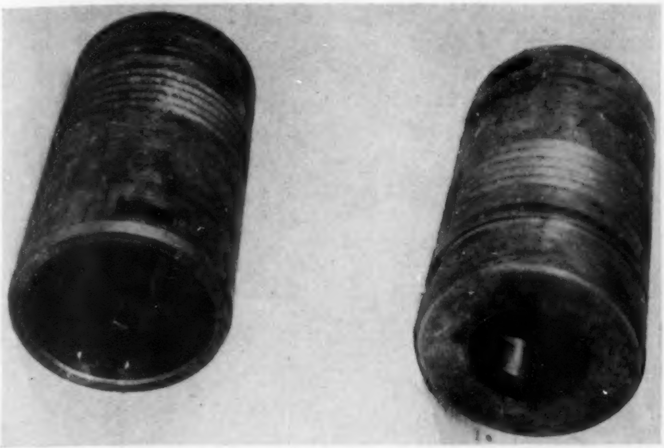


Fig. 36—Dies for the Cylinder Barrel Casting. Left—Jig for Holding Plug Firmly in Place. Right—Core Inserted to Prevent Splashing.

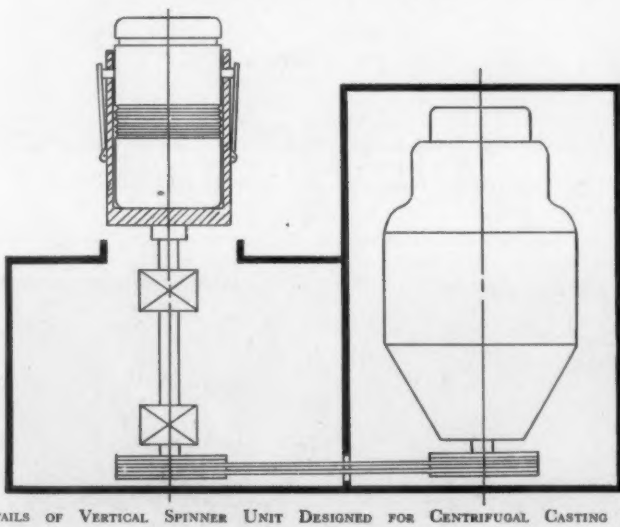


Fig. 37—Details of Vertical Spinner Unit Designed for Centrifugal Casting of Aeroplane Cylinder Barrel.

37. After the additions have been made and well-rabbled into the bath, the metal is brought to pouring temperature (3050 °F.) and slagged off, and is then ready to pour (Fig. 39). A weighed ladle is used and the metal checked on the scale to 48 lb. This governs the inside diameter. The metal is then poured into the spinning die (Fig. 40) after it has been deoxidized with 1½-oz. of aluminum and 3 oz. of ferromanganese, sufficient time elapsing for these elements to perform their function. The metal is poured into the die at 2830 °F. The optical pyrometer man carefully checks this temperature in

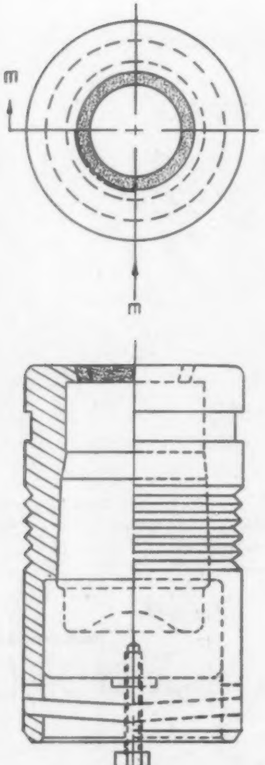


FIG. 38—SECTION OF AEROPLANE CYLINDER BARREL IN RELATION TO CASTING, WITH END PLUG AND CORE.

FIG. 39—GENERAL VIEW OF THE LAYOUT FOR CENTRIFUGAL CASTING OF THE CYLINDER BARREL.

every ladle. The die spins at a speed of 1200 rpm., and after pouring is allowed to spin for two minutes. It is then removed from the spinner, the end plug is taken out, and the casting dropped, as shown in Fig. 41.

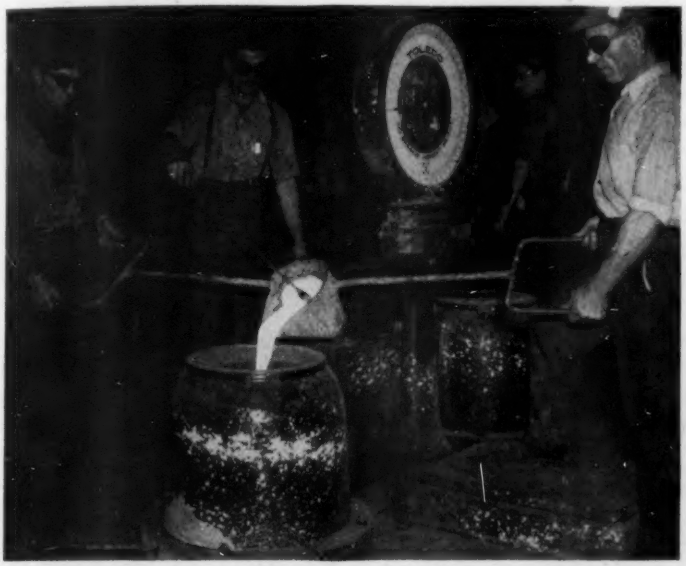


FIG. 40—POURING OPERATION FOR CENTRIFUGALLY CAST AEROPLANE CYLINDER BARREL.

FIG. 41—REMOVAL OF CYLINDER BARREL CASTING FROM THE DIE BY SLIDING DOWN THE METAL TROUGH AND STOPPING THE DIE SMARTLY, ALLOWING THE CASTING TO FALL OUT.

38. The dies used are cast in the foundry from metal which has the following composition:

	Per Cent
Carbon	0.38 to 0.45
Manganese	0.70 to 0.90
Silicon	0.30 (max.)
Sulphur	0.05 (max.)
Phosphorus	0.05 (max.)

The life of the die is approximately 500 castings. The plugs in the bottom are either concave or convex, as shown in Fig. 42. Although it makes but little difference, the convex type has been adopted to standardize the process. The life of the plug is slightly less than that of the die, as it takes the full drop of the molten metal.

39. The aeroplane cylinder casting is normalized at 1750 °F. for 8 hr., cooled in air and drawn at 1250 °F. for 6 hr. A rough cut is made on the inside and outside diameter, and the casting is then ready for the final heat treatment. This consists of a quench in oil from 1550 °F., with a pressure spray for circulating the oil on the inside of the casting. It is then drawn to a Brinell hardness of 285 to 321. Microstructures of the steel are shown in Fig. 43, (A) after normalizing at 1750 °F., (B) final structure, magnification x100 and (C) final structure, magnification x1000.

40. Various physical tests (Table 5) have been conducted on these cylin-

Table 5

AVERAGE PHYSICAL PROPERTIES OF CENTRIFUGALLY CAST STEEL CYLINDERS

Elastic limit, psi.	120,000 to 130,000
Ultimate strength, psi.	130,000 to 150,000
Elongation in 2 in., per cent	10 to 14
Reduction of area, per cent	20 to 30
Izod, ft. lb.	18 to 22

FIG. 42—TYPES OF END PLUGS USED IN CYLINDER BARREL DIE. EITHER TYPE MAY BE USED.

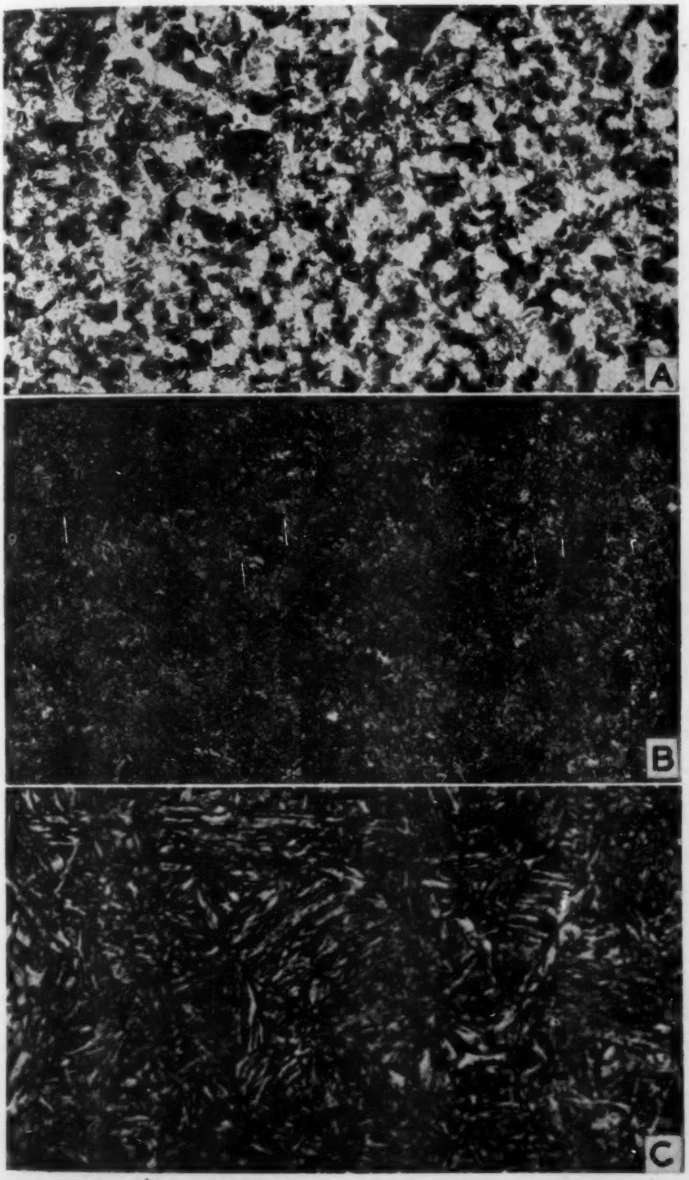


FIG. 43—(A) MICROGRAPH SHOWING UNIFORM STRUCTURE OF CENTRIFUGALLY CAST STEEL AFTER NORMALIZING AT 1750 °F. MAGNIFICATION ×100. (B)—MICROGRAPH SHOWING FINAL STRUCTURE (SORBITE) OF CENTRIFUGALLY CAST STEEL. MAGNIFICATION ×100. (C)—SAME AS (B). MAGNIFICATION ×1000. ALL NITAL ETCHED.

ders. Regular production tests submit them to 750-lb. oil pressure with careful checking for the most minute seeps. On a destruction test, they invariably withstand a pressure of 8000 lb. before bursting. Current reports from the Air Force on this cast cylinder state that it outwears the forged cylinder three to one.

41. The macro-etched cylinder section shown in Fig. 44 well illustrates the statement previously made that the casting is difficult to make due to the heavy section. The porous section increases in direct proportion to the thickness of the casting. The radiograph (Fig. 45) bears this out. Both Figs. 44 and 45 are of sections of the "as cast" sample.

Green Sand Spinning

42. In all our work in centrifugal casting, it has always been our ambition to replace the dry sand with green sand. About a year ago we started, experimentally, with this thought in mind. It is generally accepted that the core oils, mixed with the foundry sands and baked in an oxygen atmosphere, coagulate to bind the grains of sand tightly together, thereby enabling the sand cores to withstand the pressure of the molten metal. In green sand practice, small amounts of fireclay flour and bentonite with water together with flasks and weights overcome this pressure. We wanted a sand condition that could replace the dry sand cores. In other words, we wanted to make green sand molds that could be handled and stacked, similar to the sprocket cores, without the use of flasks.

43. The thought behind this was a synthetic sand line. The sand, coming down from overhead hoppers, would be made into molds on a squeeze machine and transferred to an air-drying conveyor. From the end of this conveyor the cores would be removed and assembled in much the same fashion as our regular "christmas tree" formation of dry sand spinning. After pouring the assembly would be transferred to a cooling conyevor, and from the cooling conveyor to the shake-out. A fines drum would remove the fines. A roller magnet would take out the metal. A pug mill could be used to aerate and break up the sand. From the pug mill the sand would be transferred to a vertical chain elevator through a squirrel cage aerator and into hoppers above the mixers. In the mixers the sand could be mulled with the necessary additions and returned to the hoppers above the molding machines.

Sand Mixture

44. To perform this function, a sand had to be developed that would withstand the pressure of the centrifugal action of the metal. Various mixes were tried, but the ideal batch was bonded with a compound, the principal ingredient of which was halloysite. A 12.5 per cent addition of this compound to our sharp sand gives a sand of the characteristics shown in Table 6.

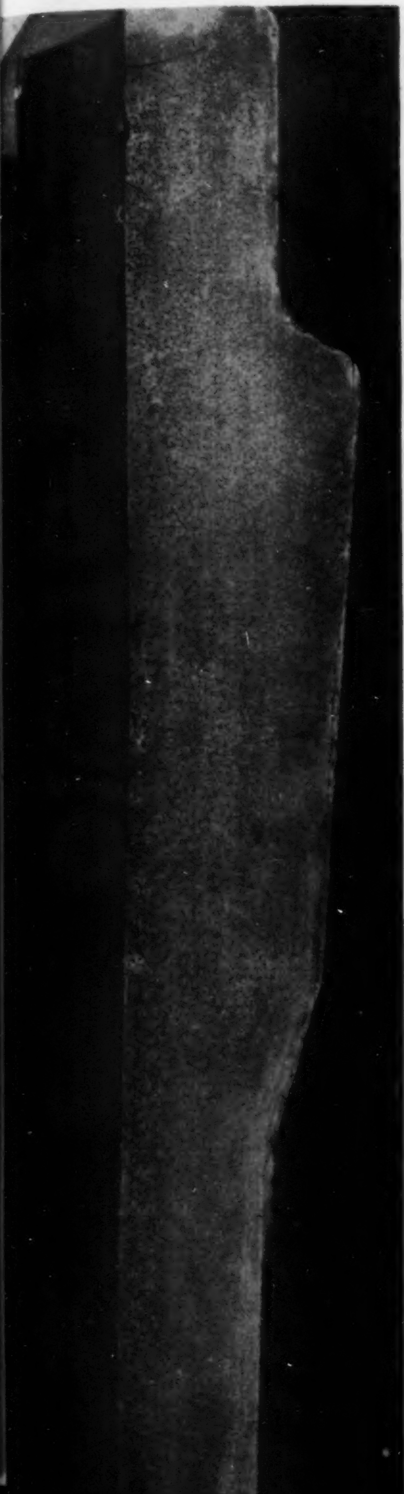


FIG. 44—MACROGRAPH OF CENTRIFUGALLY CAST CYLINDER BARREL SECTION. NOTE INCREASED POROSITY DUE TO THICKNESS OF CASTING.

FIG. 45—RADIOGRAPH OF CYLINDER BARREL SECTION SHOWN IN FIG. 44.

Table 6

SAND CHARACTERISTICS AFTER VARIOUS NUMBER OF BLOWS OF A.F.A. STANDARD RAMMER

No. of Rams	*3*	*5*	*10*	*15*
Weight of Specimen, grams	166	169 plus	175.0	179.0
Water, per cent	1.7	1.7	1.7	1.7
Flowability	85	85	85	85
	87	87	87	87
Deformation, in. per in.	0.005	0.011	0.017	0.021
	0.007	0.010	0.0185	0.022
Permeability	165	155	115	100
	165	155	115	100
Green Compression Strength, psi.	3.7	4.7	6.6	7.4
	3.7	4.8	6.6	7.6
One Hour Air Dry				
Compression Strength, psi.	8.9	12.0	16.0	18.0
	8.0	12.5	14.0	20.0
Hardness	91	95	95	96
	90	95	96	97
Ten Hours Air Dry				
Compression Strength, psi.	44.5	61.0	69.5	75.5
	40.0	57.0	71.0	73.0
Hardness	94	94	96	96
	95	95	96	97

45. The values shown in Table 6 for five or more rams indicate the strength increases obtainable with greater pressure. In practice, the pressures used are much greater than those produced with the additional ramming.

46. The molding practice consists of a pattern, fixed to a jolt-squeeze machine. A predetermined amount of sand is spread over the pattern and a calculated high pressure is applied. The pattern and plate are slid from the machine and turned over and stripped. A well-perforated plate is used to allow as much air as possible to contact the bottom surface of the mold. After the mold is set an alcohol-base spray is used on the parts of the mold that come in contact with the metal. This spray consists of one part alcohol, one part core oil and one part glutrin.

47. Halloysite is added until a specific gravity of 55 °Bé is obtained. The molds are sprayed cold, no torch being necessary to make the skin dry.

48. Using this sand and system of molding, casting clusters, such as the sprocket (Fig. 2) and the bearing (Fig. 12), were spun in green sand without the use of supporting flasks. Figure 46 shows a cluster of crankshafts, employing the "umbrella gate," which were spun in green sand. Note the location of the riser on top, which is located ahead of the individual casting, the metal to be fed into the casting as it spins anti-clockwise.

Machine Tool Steel Castings

49. A great deal of experimenting with this sand has been done with tool

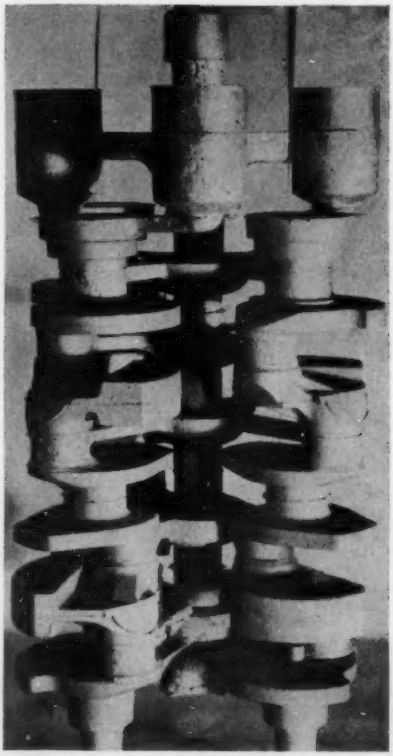


FIG. 46—A SPUN CLUSTER CASTING OF CRANKSHAFTS CAST IN GREEN SAND.

steels, our chief reason for this being that a 200-lb. induction furnace can be used to supply the metal, and the type of casting for a tool gives the sand a trying test. Figure 47 shows a stagger-tooth milling cutter, as cast. This is a spun casting, green sand with Juanita bank sand instead of sharp sand being used to produce a better finish. Figure 48 shows the tool ready for use. Very little machining is required on this cutter. The analysis is as follows:

	Per Cent
Carbon	0.70
Tungsten	18.00
Chromium	4.00
Vanadium	2.00

The casting, in its application on repeated tests, has outlasted similar tools cut from bar stock.

50. Figures 49, 50, 51 and 52 show various machine tools which were centrifugally cast in green sand. Various types of gating have been employed to produce these castings. They clearly illustrate the close dimensions that can be held in work of this nature. Figure 49 shows a four-lip core drill that was spun from a steel alloy of 18 per cent tungsten, 4 per cent chromium and 2 per

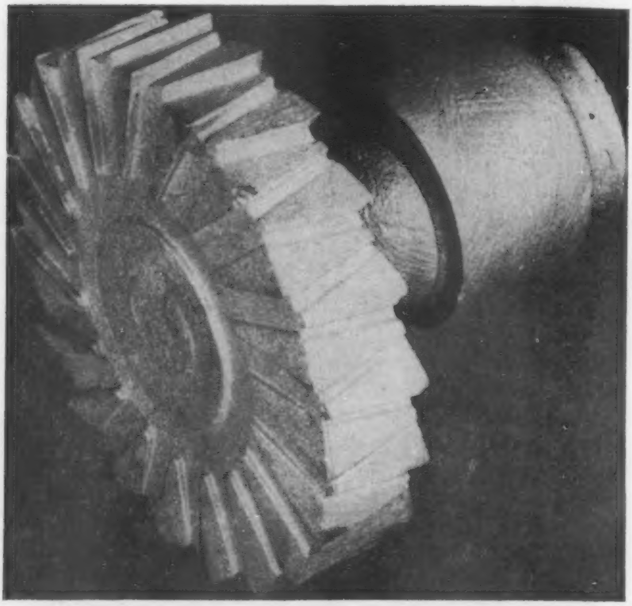


FIG. 47—A STAGGER-TOOTH MILLING CUTTER CASTING SPUN IN GREEN SAND.

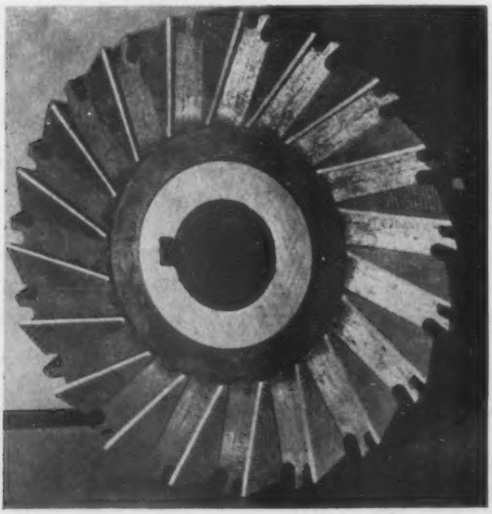


FIG. 48—THE FINISHED MILLING CUTTER FROM CASTING SHOWN IN FIG. 47.

cent vanadium. Figure 50 shows a side milling cutter tool. We have been casting this type of tool for the past two years, but in the form of a blank. Figure 51 shows another casting that has lately developed from the blank form into a "cast to size" type. It is interesting to note the two forms of gating. In the side milling cutter, the center sprue goes through the casting

and two small gates feed it from the bottom, while in the slab milling cutter two gates come from the center sprue, feeding into the top of the casting. Still another type of feeding is employed in casting a hob milling cutter (Fig. 52). The trick to this casting is in making the green sand mold, employ-

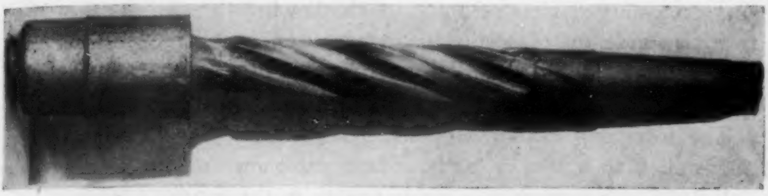


FIG. 49—A FOUR-LIP CORE DRILL CASTING SPUN IN GREEN SAND.

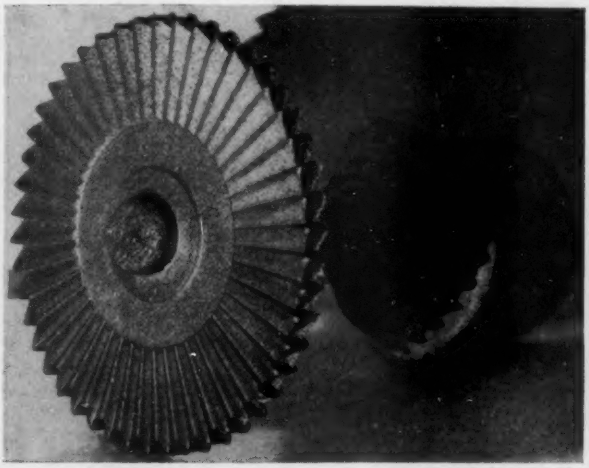


FIG. 50—A SIDE MILLING CUTTER CASTING SPUN IN GREEN SAND.

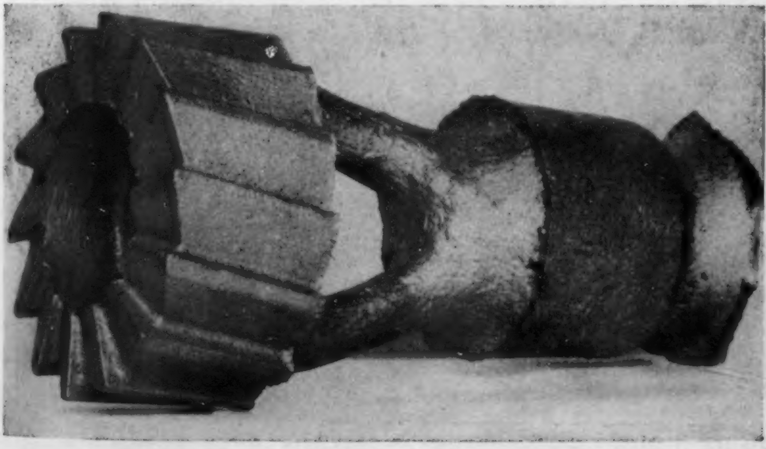


FIG. 51—A SLAB MILLING CUTTER CASTING SPUN IN GREEN SAND.

ing a device called a "snake." This "snake" consists of loose pieces that are hinged together and which is drawn from the mold by means of folding inward, leaving clearance to remove it.

51. Figure 53 (top) shows a spline broach spun in green sand and (bottom) an enlarged view of this broach showing the details more clearly. The mold is made up of sections. Each section has the impression of one group of teeth. Top and bottom sections are clamped on. The assembly is held in a special adaptor pot for spinning.

52. The foregoing examples open up an entirely new field for the spinning of metal. The results so far have been most encouraging, and we expect to investigate much more of this type of work in the future.

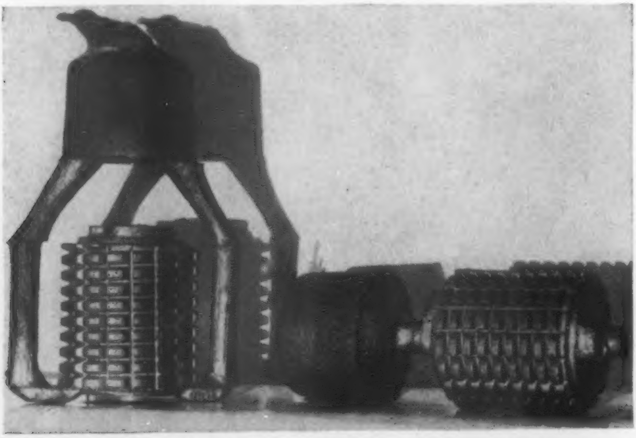


FIG. 52—A HOB MILLING CUTTER CASTING SPUN IN GREEN SAND.

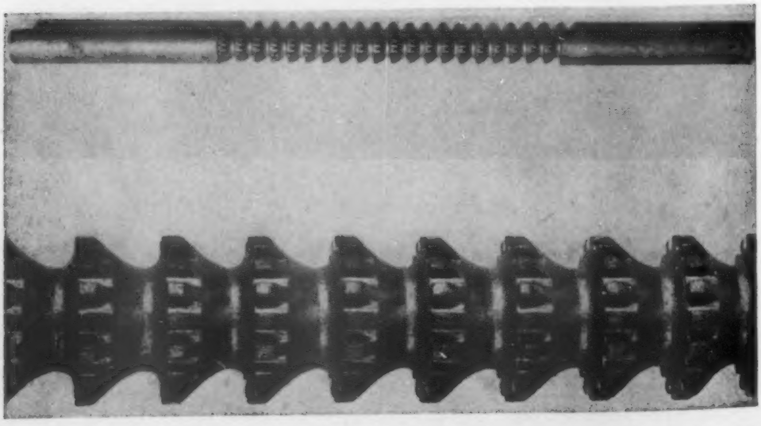


FIG. 53—TOP—A SPLINE BROACH CASTING SPUN IN GREEN SAND. BOTTOM—ENLARGED SECTION SHOWING DETAILS.

CONCLUSION

53. In a paper of this nature, the conclusions are rather difficult to correlate. We feel that our work is merely a beginning for the future development of centrifugal castings. The conclusions will be more complete when the hundreds of applications, which present themselves, have been investigated. By the same token, the type of work proven in this article is bound to suggest to its readers other projects to which centrifugal methods are applicable. We have poured into spinning molds practically every type of commercial metal including the following:

Magnesium	Brass
Aluminum	Zinc
Copper	Tool steels
Chromium copper	Various SAE steels
Beryllium copper	Carbon steels
Manganese bronze	Malleable iron
Phosphorus bronze	Cast iron

Metal Combinations

54. Combinations of metals have been tried with good results. For example, a given amount of steel was poured at 1200 rpm. Sufficient time was allowed for partial solidification and then a bearing mixture (65 per cent copper and 35 per cent lead) was poured into the die. The result was a well-knit steel jacketed bushing which withstood a 350-ton pressure applied in an endeavor to separate the bearing metal from the steel. Various other combinations of the previously mentioned metals have been tried with gratifying results, the most difficult of which was the application of a steel liner to a magnesium jacket. By means of using a latent gas, careful timing and temperature control of metals, a sound combination resulted.

55. However, in this conclusion, some time should be spent on the advantages of centrifugal casting. There really are only two major items that govern our methods, and those are cost and quality.

Cost

56. One of the biggest advantages of centrifugal castings over static castings is the closeness to which finished dimensions can be held. It is a common occurrence in foundry practice today to allow ¼-in. or better for machined surfaces. Forgings, in particular, require a great deal of machining to produce a finished article. In centrifugal practice, this allowance for machining can be held to 1/16-in. There are innumerable metal products on the market today that are either forged or statically cast, followed by machining operations which, if the part had been spun to size, would not be required.

57. Another predominating factor in the cost is the yield attained with centrifugal castings. Metal at the spout is represented in dollars and cents,

and the more metal that can be consolidated into sound castings in relation to sprue, the lower the cost of producing that metal. Not only is the saving in remelting, but the handling and storage of the sprue is a large cost factor. Our average yield on centrifugal steel casting is 80 per cent, with some jobs running as high as 90 per cent.

Quality

58. The centrifugal casting method is the most ideal condition which can be attained in foundry practice. By this method the science of metallurgy is harmonized with the art of coremaking and molding. This has been proved in actual practice where we have obtained physical properties in castings 10 to 15 per cent greater than in forgings.

59. In a forging, the metal, by means of hammering or working, is forced into shape. To a certain extent, the grain structure is disrupted. In the centrifugal system of naturally packing the grains, an ideal condition is attained. However, it must be borne in mind that a relationship between the revolutions per minute and the temperature of the molten metal entering the mold must be established for the different types of metal used.

60. It is also important, from a metallurgical standpoint, to see that the metal is poured from the furnace at a temperature sufficiently high to allow the deoxidizers to complete their reaction. By this means any non-metallic inclusions have been eliminated. Upon entering the mold, any minute particles remaining will terminate, by centrifugal action, in the center sprue. Uncombined gases, by the same token, are forced out of the castings, and no intricacy of design can prevent the metal from filling out the mold cavities to the exclusion of anything lighter in weight than the metal itself. All of these conditions combine to produce a fine quality, low cost steel casting which is our fundamental purpose.

ACKNOWLEDGMENT

61. The writers wish to express their appreciation to W. R. Campbell, president of Ford Motor Company of Canada, Ltd., for his interest and encouragement in this work and for permission to publish this paper.

DISCUSSION

Presiding: DR. A. E. SCHUH, U. S. Pipe & Foundry Co., Burlington, N. J.

Co-Chairman: J. B. CAINE, Sawbrook Steel Castings Co., Lockland, Ohio.

ERLE J. HUBBARD[1] *(written discussion):* It is indeed noteworthy to find that information such as just presented is becoming available to aid the industry. The authors are to be complimented on their fine work.

[1] Research Laboratory, Koppers Co., American Hammered Piston Ring Div., Baltimore, Md.

We have been experimenting for some time with the true or horizontal method of centrifugal casting, and the results are most encouraging. Centrifugal casting is not a cure for all diseases of static castings, although it does, in many cases, offer decided advantages not only from the cost side but also from the increased physical properties obtained.

Many of the same casting difficulties encountered in static casting are also found in centrifugal casting, such as hot tears, pouring temperatures, etc., but, usually, the conditions are not quite as critical.

We, in the piston ring industry in the United States, have known for some time that other countries were manufacturing piston rings from centrifugally-cast piston ring pots, but because we were established on statically-cast individual rings for the most part, and results obtained apparently were satisfactory from the standpoint of physical properties, we have not investigated the centrifugal casting method until recently.

We have investigated this method enough to know that there are some decided advantages that can be obtained with proper metal composition; for example, a decided increase in impact strength and the modulus of elasticity.

Most of our work has been done with permanent metal molds, and we went through a host of difficulties with castings sticking to the mold and to the detachable front and rear plates. After considerable experimentation, a molybdenum cast iron mold and baked sand cores, backed by steel plates for the front and rear of the mold, proved to be successful. We were wondering if the authors have any experience in the preheating of permanent molds. To date, we have been heating the molds to a temperature of 600 to 700° F. before spraying with the mold wash. Our metal usually is at a temperature of 2850 to 2900° F. when it enters the mold. The material is a composition containing small amounts of chromium, nickel and molybdenum calculated to give white cast iron in the 3.00 per cent carbon, 1.25 per cent silicon range. As yet, we have not traced any difficulties to the temperature of the mold, but have been informed from time to time that it was important. Is the temperature of the mold before casting critical?

Do the authors have any information regarding the use of steel plates at the front and rear of the mold? Our mold is very similar to that shown in Fig. 36. In some cases, when we used cast iron and also low carbon steel plates, we found that the casting had actually "burned" or eroded about ½ in. into a one-in. and 1½-in. thick plate. The wall thickness of most of our castings is about ⅝ in., length 14 in., and the outside diameter 5¾ in. to 6½ in.

The authors also stated that in spinning a casting horizontally there was a tendency to form cracks in their particular size casting when the spinning speed was increased above 775 rpm. Is it possible that this may be eliminated by either increasing or decreasing the speed after the mold has been filled? We have recently encountered some of the authors' difficulty, occurring as a longitudinal hot tear in a cylinder with 1⅛-in. thick wall, but we have never noticed it in a casting of ⅝-in. wall thickness. The outside diameter of the casting in this case was 6½ in. and the length 14 in. The mold was spun at 980 rpm.

We have always been given to understand that if the length of the casting was twice the diameter, it was better to spin the mold on a horizontal or a slightly inclined axis rather than vertically. Do the authors have any comment on this?

MR. PERKINS *(answer to Mr. Hubbard's written discussion)*: Mr. Hubbard assumes that true centrifugal and horizontal spinning are synonymous. This is not the case. True centrifugal casting usually is defined by means of the weight of metal poured governing the inside diameter of a cylindrical shape. This can be produced both horizontally and vertically. However, in the vertical method the parabola formed has to

be taken into consideration, and it is obvious that a cylindrical shape of too great length would make this method impracticable.

We use a steel die, cast in our foundry, of the analysis shown in paragraph 38 of the paper. The temperature of the dies is maintained at between 200 and 300° F. The dies are sprayed with a light silica flour spray, and the metal poured into the die as cold as practicable operation will allow. As to the "burning in" of end plugs, etc., the trouble may be due to high pouring temperatures.

In Fig. 38 is shown a sectional view of a casting indicating the type of plug used for end plates in the bottom of the die and the core used in the top.

The tendency to crack, pouring the casting horizontally, was a result of increasing the speed of the unit to eliminate minute porosity indications. We believe that the cracks formed as a result of the vibration caused by running the horizontal machine at 1000 rpm. when the metal was in the critical cooling state.

J. A. RASSENFOSS[2]: Mr. Perkins mentioned that the green sand molds used for centrifugal work were made up with precalculated high pressures. What were the order of those pressures, approximately how were they applied, and through what range of depths of cores are they applicable to give good results?

MR. PERKINS: We have not definitely established the pressure as yet. We took the patterns for making the statically-cast crank shafts and put on a predetermined amount of sand and then applied about 500 psi. pressure on those particular cores for the crank shafts. The surprising part about it, and why we are so interested in it and why we intend to keep after it, is the fact that after the core was stripped from the pattern and laid aside, in a matter of 5 or 6 min. it could be picked up by a corner.

The dimensions are about 14 x 14 by one in., in some cases ranging up to 2½ in. for the heavy core on top.

W. E. MAHIN[3]: What are the properties of this green sand halloysite material? Does it have to be made in a flask or can it be used as the cores are, without support?

MR. PERKINS: We have a typical foundry production molding line, and we are running a rather tricky casting for a universal carrier. It is a bogey bracket arm and has a green sand cope and drag. Each arm is cored out and a large core is placed between the two arms. Various other cup cores, etc., comprise the assembly. We were running across a cracking condition between the arms, indicating a too rigid core. We put a bench coremaker right beside the line and let him make the cores up and put them aside. After they had stood about ½ hr., the core setter would set them in the mold, and some wonderful results were attained.

As to the properties of halloysite, it is a siliceous material with a very high fusion point (3400 to 3500° F.), and this enables us to use it as a molding medium. The high fusion point gives that much more resistance to the corrosive effects of the metal.

MR. MAHIN: You would still have the properties of the green sand, however.

MR. PERKINS: Yes. There are no flasks used. By the same token, we are trying to develop a spray that will not require skin drying, etc. We have accomplished it in quite a number of jobs, especially the tool steel. In fact, we feel confident enough to design our lines to take care of the production of green sand stacks of these sprockets and bearings.

[2] American Steel Foundries, East Chicago, Ind.
[3] Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Centrifugal Casting of Steel

By C. K. Donoho*, Birmingham, Ala.

Abstract

The author presents the various methods and types of centrifugal casting of steel. The advantages and disadvantages of centrifugal casting, as evaluated by comparison with static casting and forging, are discussed in detail. Physical properties of steel cast centrifugally under various conditions are given. The effects of various treatments on the structure and properties of centrifugally cast steel are discussed, emphasis being placed on deoxidation procedure.

1. The direct forming of useful engineering parts from liquid steel by centrifugal casting is not new[1], but there has been a remarkable expansion in this field since the beginning of the war emergency. Use of centrifugal methods enables the foundryman to produce castings more uniform in properties and consistently more free from defects. Centrifugal casting also has enabled foundries to produce successfully parts formerly available with suitable quality only in the form of forgings. For evaluation of centrifugal casting there are, then, two separate criteria for comparison; static casting, and forging.

Advantages of Centrifugal Casting

2. Compared to static steel casting, centrifugally cast steel may realize the following principal advantages: (1) increased soundness and cleanliness, (2) higher yield, (3) simplified inspection, and (4) adaptability to mass production. Compared with forging, centrifugal casting may show the following advantages: (1) producing parts nearer to finished dimensions with consequent saving in machining, (2) lower equipment cost than for forging dies and presses, and (3) production of parts free from directional properties.

3. This paper does not intend to imply that centrifugal casting is a panacea to cure all casting troubles. Compared to static casting there are limitations of size and shape, and the expense of installing and maintaining spinning equipment. Compared to forging, there is the lack of opportunity to completely test the steel before forming the part, and the lower tensile ductility in the longitudinal direction.

---

*Metallurgist, American Cast Iron Pipe Company.

[1] Superior numbers refer to references at the end of this paper.

Note: This paper was presented at a Centrifugal Casting Symposium Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 28, 1944.

4. All rolled or forged steel has the grains and non-metallic inclusions elongated in the direction of rolling with the result that the properties obtained when the part is stressed perpendicularly to the flow lines are quite different from those obtained by testing in the longitudinal direction. The grain structure of castings is changed only by heat treatment, and the non-metallic are practically unalterable in size, shape, and distribution. A sound, heat-treated casting, however, does have equal properties when tested in any direction.

5. This inherent structural difference between castings and forgings is often an advantage in favor of the casting. Cone[2] has reported bursting tests of forged and centrifugally cast aircraft cylinder barrels, where the forgings split longitudinally at significantly lower pressures than the bursting pressures of similar centrifugally cast barrels. The cast barrels also showed greater "bulge" deformation. McCarroll[3] found that centrifugally cast gears had better overall properties than forged gears.

Types of Centrifugal Casting

6. Centrifugal casting has been divided into three types: (1) centrifuging, (2) semi-centrifugal casting, and (3) true centrifugal casting. In centrifuging, molds are spaced around the periphery of revolution and the metal is flowed from a central down-gate into the molds through radial in-gates. Semi-centrifugal casting is used for wheels, gears, or other disc-shaped parts. The mold is spun about its own axis and the centrifugal force generates pressure from the center outward to the rim section. This aids feeding of the rim section and helps to achieve directional solidification.

7. In true centrifugal casting, the mold is spun about its own axis and at least a part of the useful interior surface is shaped by centrifugal force without a center core. It is only in the latter type that the full benefits of the centrifugal method accrue. Highest yields, best flotations of non-metallics, most positive elimination of shrinkage and gas pockets are obtained by true centrifugal casting.

Molds

8. The mold material for centrifuging and semi-centrifugal casting is usually sand. Various proprietary "investments" are used in specialized work. Ford Motor Company has produced gears semi-centrifugally in metal molds[3].

9. Molds for true centrifugal casting are either sand or metal. Each type has its advantages[4]. A metal mold, or die, which may be used for hundreds of castings is preferred for cylindrical parts which are not of excessive length. The presently preferred metal mold material is either soft gray iron or low carbon steel.

AXES

10. Centrifuged and semi-centrifugal castings are most commonly spun about the vertical axis. These processes are adaptable to stack molding. True centrifugal castings are usually spun about the horizonal axis, in which case the interior formed by centrifugal force is perfectly cylindrical and is exactly determined by the mold dimensions and the quantity of metal poured.

11. True centrifugal castings in some cases are spun about vertical or inclined axes[6]. The cavity formed by spinning about any axis other than the horizontal is paraboloidal. The shape of the cavity may be calculated by the following, which is the equation of the parabola at a section through the axis line:

$$H = \left(\frac{0.0000142\,N^2}{\sin B}\right) R^2,$$

Where: H—height above vertex in inches.
N—spinning speed, rpm.
B—angle of inclination of axis.
R—radius of cavity.

12. Figure 1 shows calculated shapes for vertical axis casting at several spinning speeds. It has been shown experimentally (Fig. 2) that the calcula-

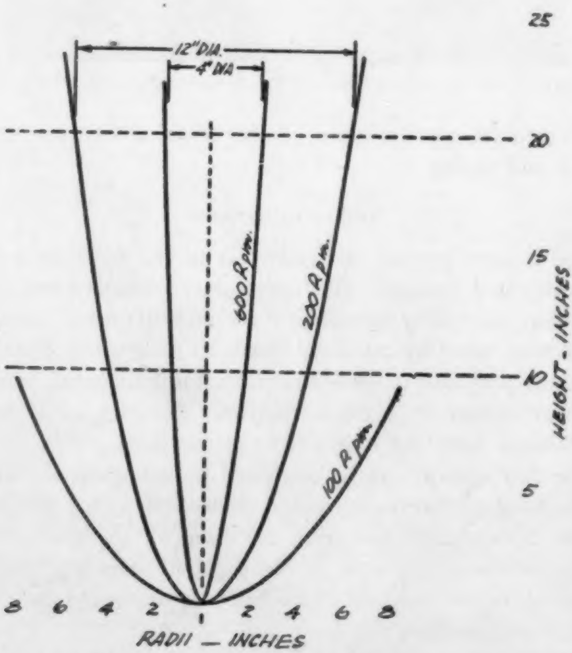


FIG. 1—CALCULATED SHAPES OF CAVITY IN VERTICAL CENTRIFUGAL CASTING.

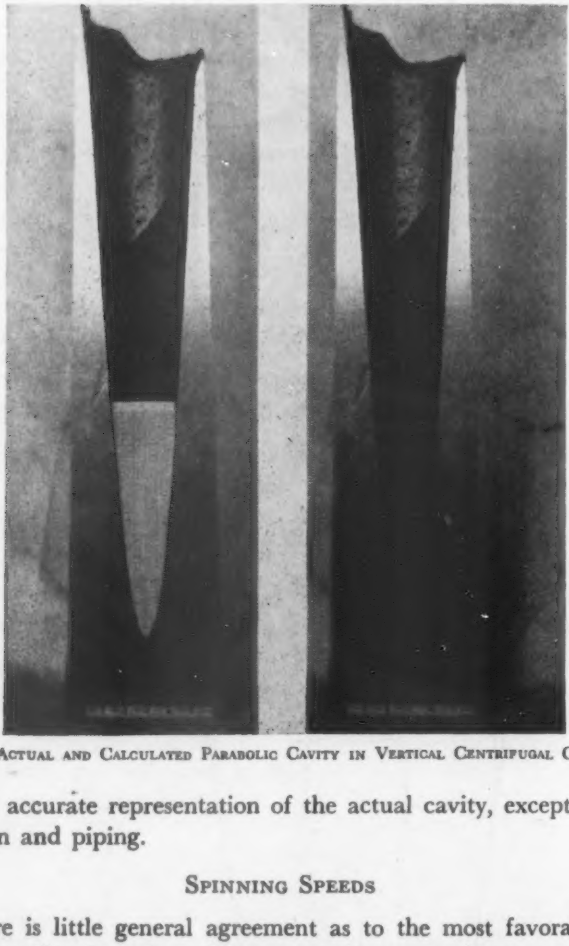


FIG. 2—ACTUAL AND CALCULATED PARABOLIC CAVITY IN VERTICAL CENTRIFUGAL CASTING.

tion gives an accurate representation of the actual cavity, except as modified by contraction and piping.

SPINNING SPEEDS

13. There is little general agreement as to the most favorable spinning speeds for centrifugal casting. The uncertainty extends even to the proper type of equation to relate favorable rpm. and diameter. In vertical axis spinning, it is most usual to calculate speeds to maintain a certain peripheral velocity. This system also is used sometimes for horizontal, true, centrifugal casting. Another system is to relate speed to diameter so as to maintain a constant centrifugal force per unit weight of metal.

14. These two systems can be expressed by equations but are more conveniently calculated by the nomographic charts herewith presented in Figs. 3 and 4. In Fig. 3, a straight line from the diameter to the desired peripheral velocity will cross the center scale at the required spinning speed. In Fig. 4, a straight line to the desired centrifugal force figure crosses the center scale at the rpm. which will generate this force.

15. In vertical semi-centrifugal casting of gears, Wright and Caine[6] use

450 to 600 surface ft. per min. peripheral speed. Other experimenters have used speeds from 200 to 1000 ft. per min. In centrifuging and semi-centrifugal casting, where the centrifugal force acts only to furnish pressure or to throw the first—and coldest—metal to the periphery, the speeds used are not critical and are more often determined by practical exigencies than by physical theory.

16. Spinning speeds are more critical in true centrifugal casting. An insufficient speed will not "pick up" the metal on the mold wall and will allow slipping or "raining" until the metal is nearly solidified. This may cause laps and entrapped oxides. Excessive spinning speed can produce circumferential tension high enough to cause longitudinal hot tears in the solidifying steel as it shrinks away from the mold wall. Between these extremes there is a range of favorable speeds.

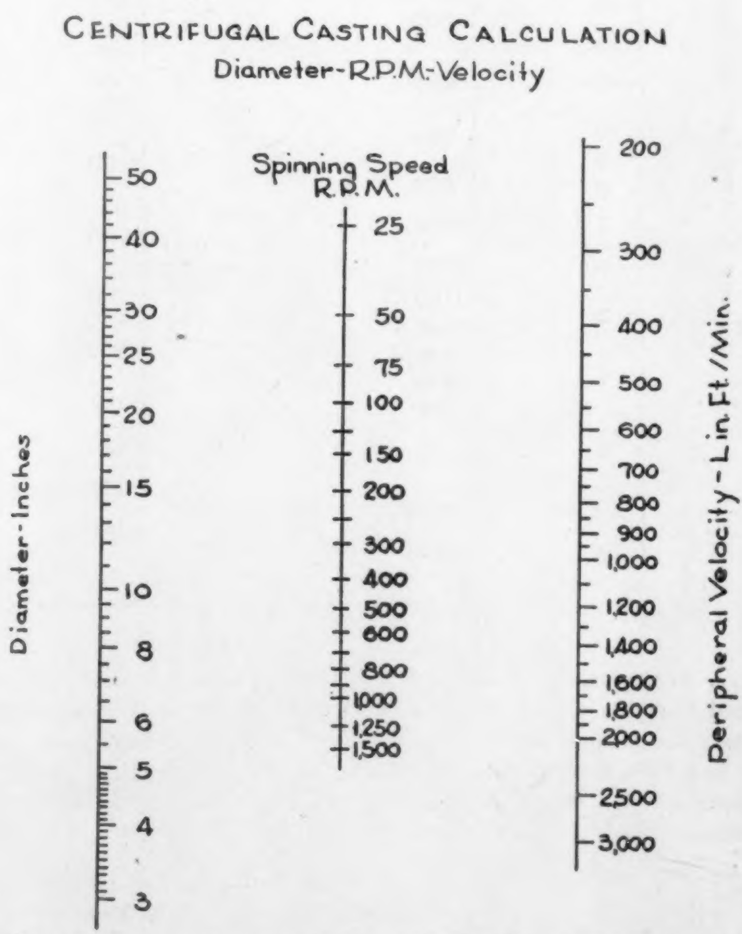


Fig. 3—Nomogram for Calculating Spinning Speeds to Constant Peripheral Velocity.

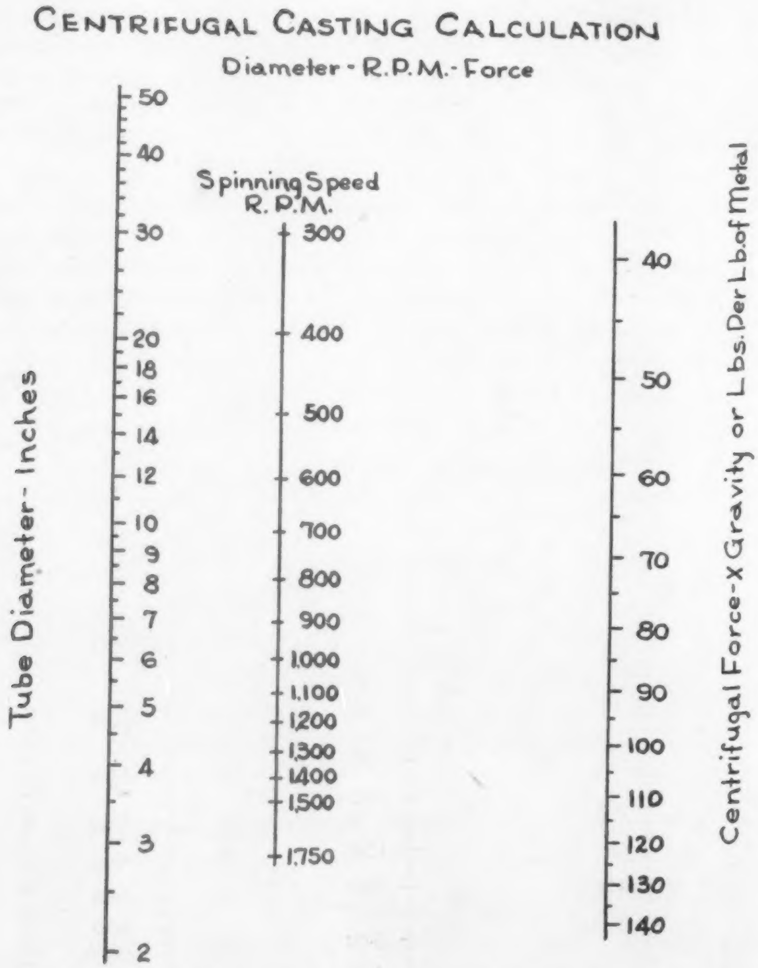


FIG. 4—NOMOGRAM FOR CALCULATING SPINNING SPEED TO CONSTANT CENTRIFUGAL FORCE.

17. At the writer's plant, for true centrifugal casting in sand lined molds, a speed to give a centrifugal force of 75 times gravity at the inside diameter has been found most satisfactory. For very thick-walled castings, or castings with large diameter flanges, it may be necessary to select a compromise diameter for the 75*g* to avoid having excessive force at the largest outside diameter.

18. The molten metal "picks up" more readily on metal molds than on sand molds. Usual practice for metal-mold, true, centrifugal casting is to use a speed to give a force of about 60 times gravity at the inside diameter.

TYPICAL CASTINGS

19. Figure 5 is an example of the centrifuge method using stack molding to produce a number of identical parts from a single down-gate with no risers. In Fig. 6 is shown as-cast and machined views of a typical semi-centrifugal casting made sound without risers. Figure 7 shows the same principle adapted to stack molding.

20. True centrifugal casting in sand-lined molds is illustrated in Fig. 8 by 16-ft. lengths of cast steel shafting. A product of the metal-mold, true centrifugal process is shown in Fig. 9. This process is used for mass production of highest quality cylindrical steel parts in the shorter lengths.

STRUCTURE AND PROPERTIES

21. Steel cast by centrifuging and semi-centrifugal casting is not essen-

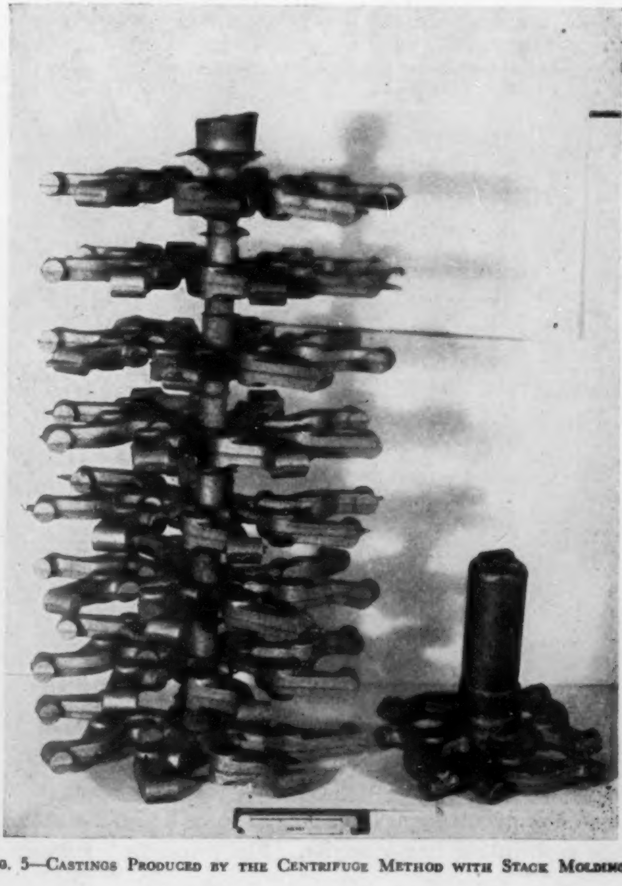


FIG. 5—CASTINGS PRODUCED BY THE CENTRIFUGE METHOD WITH STACK MOLDING.

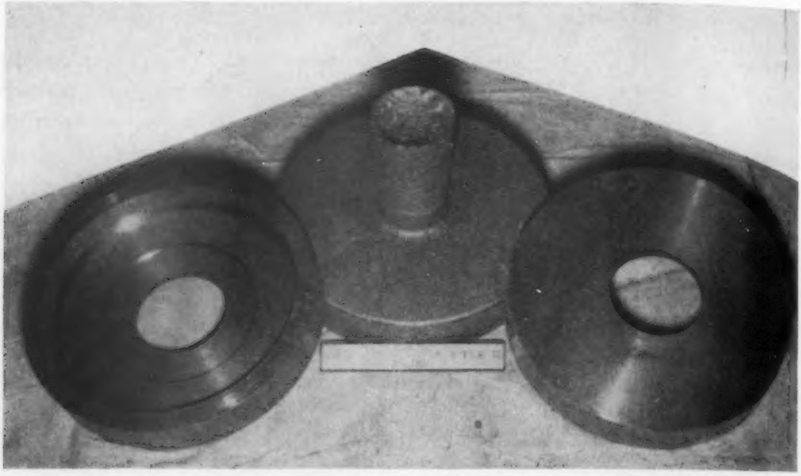


FIG. 6—FLY-WHEEL CASTING MADE SEMI-CENTRIFUGALLY. CENTER—AS-CAST. OUTSIDE—MACHINED.

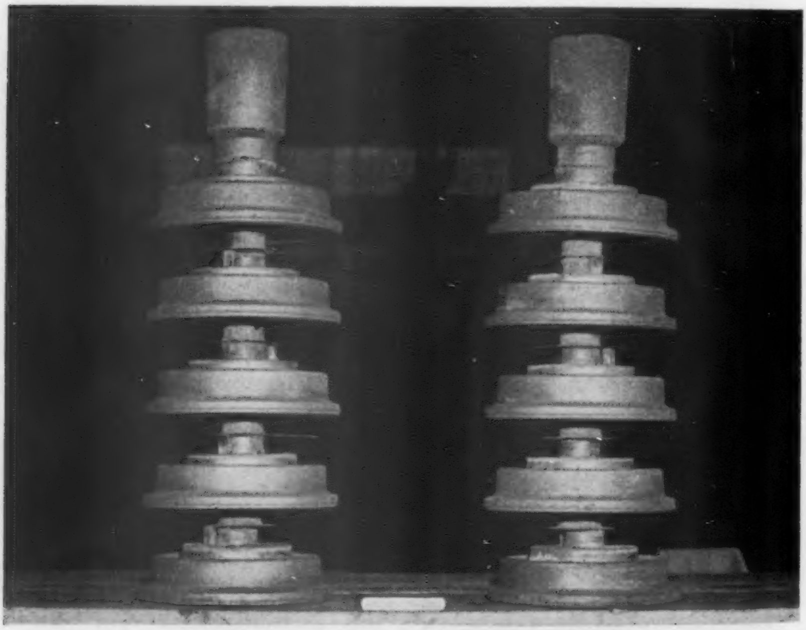


FIG. 7—TRACK-WHEEL CASTINGS MADE SEMI-CENTRIFUGALLY.

tially different in structure and properties from other steel castings. The problems of correct gating and feeding of heavy sections are ever present as in static casting. Even centrifugal force cannot force liquid metal through frozen metal to feed a shrinking heavy section. The principles of design to produce

sound semi-centrifugal castings have been treated adequately by Wright and Caine[6].

22. In true centrifugal casting, internal shrinkage cavities do not normally occur. Freezing begins at the outside surface of the casting next to the mold wall and progresses inward to the inner surface, which should be the last to

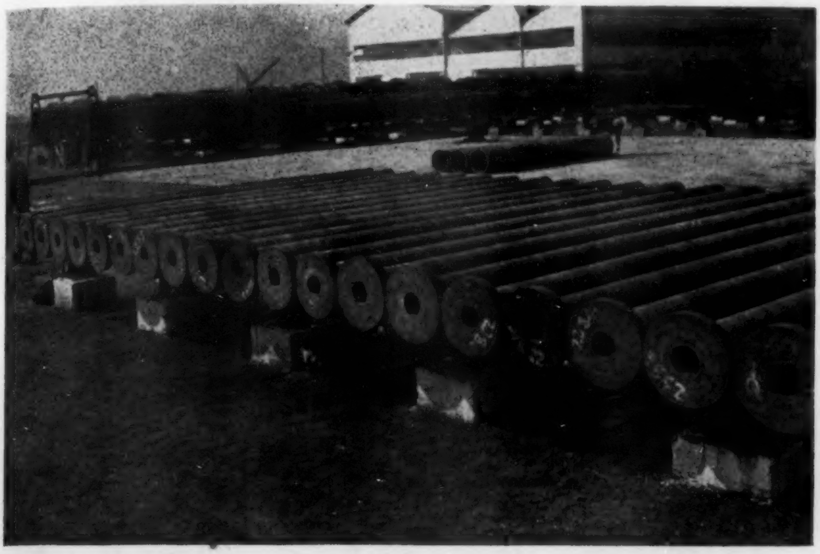


FIG. 8—STEEL SHAFTING CAST IN 16-FT. LENGTHS BY TRUE CENTRIFUGAL METHOD.

FIG. 9—RADIAL ENGINE CYLINDER BARREL CASTING. LEFT—AS-CAST. CENTER—ROUGH MACHINED. RIGHT—FINISHED.

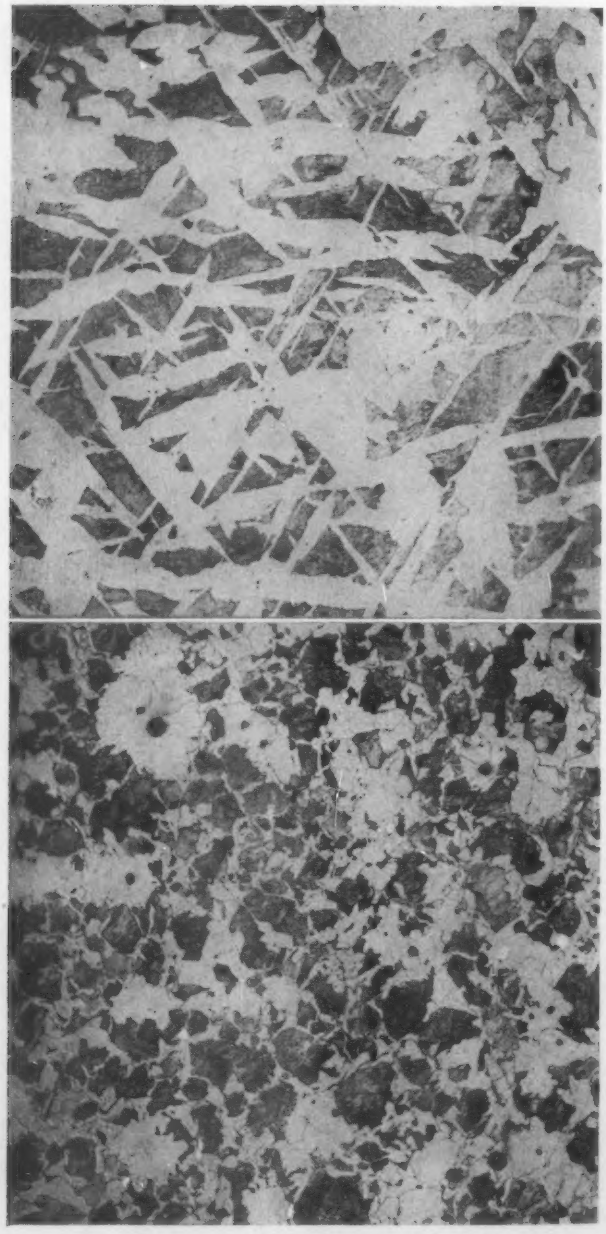


FIG. 10—MICROSTRUCTURES OF 16-FT. LONG SHAFTING CASTINGS SHOWN IN FIG. 8—TOP—AS-CAST. BOTTOM—ANNEALED, ETCHED, MAGNIFICATION x100.

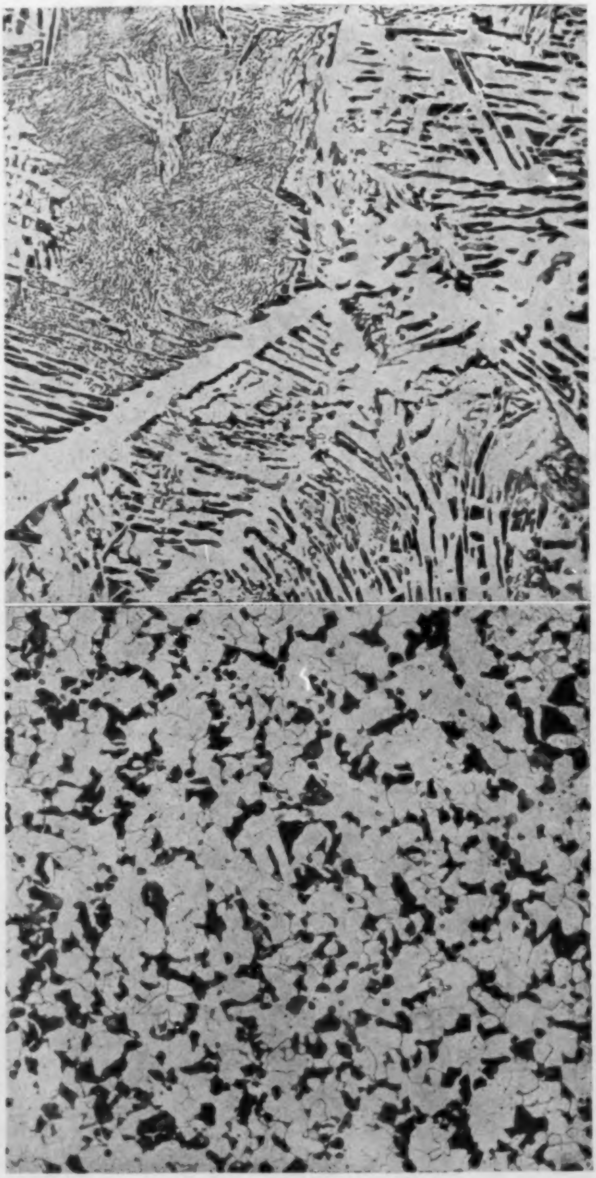


Fig. 11—Microstructures of Medium Carbon Steel Cast Centrifugally in a Metal Mold. Top—As-Cast. Bottom—Normalized. Etched, Magnification x100.

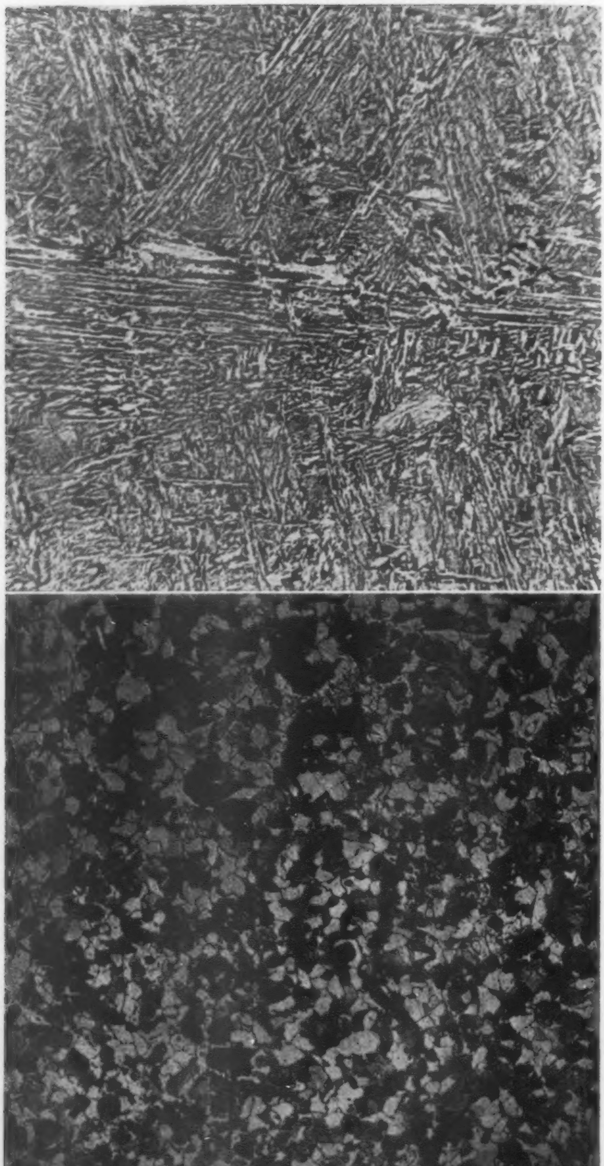


FIG. 12—MICROSTRUCTURES OF METAL-MOLD, CENTRIFUGALLY-CAST, ALLOY STEEL. TOP—AS-CAST. BOTTOM—NORMALIZED AND TEMPERED. ETCHED, MAGNIFICATION X100.

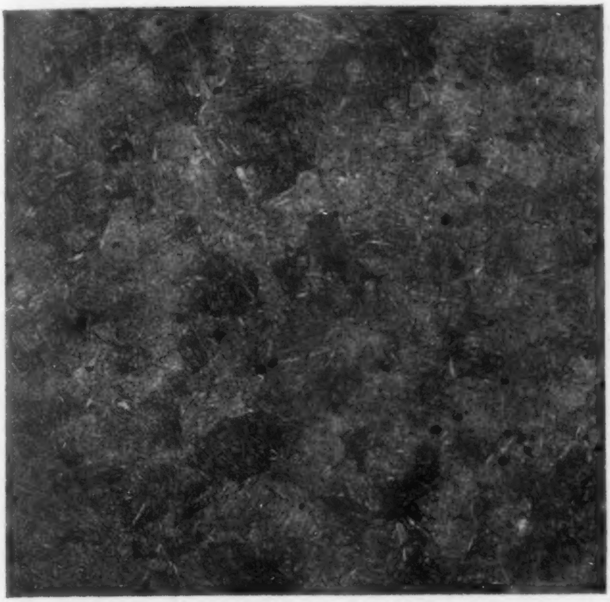


FIG. 13—SAME AS FIG. 12, OIL QUENCHED AND TEMPERED.

Table 1

RESULTS OF TESTS ON STANDARD 0.505-IN. DIAMETER TENSILE TEST SPECIMENS FROM HEAT-TREATED CENTRIFUGAL CASTINGS, METAL FOR WHICH WAS PREPARED WITH AND WITHOUT ALUMINUM DEOXIDATION

Heat No.	Aluminum Added for Deoxidation, Per Cent	Composition, Per Cent C	Mn	P	S	Si	Cr	Mo	Al*
11457	None	0.43	0.83	0.028	0.032	0.41	0.90	0.18	0.01
11486	None	0.39	0.81	0.025	0.033	0.34	0.97	0.17	0.01
11461	0.125	0.43	0.92	0.024	0.033	0.49	0.95	0.19	0.029
11480	0.125	0.41	0.98	0.027	0.029	0.50	0.98	0.20	0.067
11500	0.125	0.40	0.94	0.023	0.031	0.29	0.98	0.18	0.093

MECHANICAL PROPERTIES

Heat No.	Special Deoxidation	Mechanical Properties Tempering Temp., °/F	Tensile Strength, psi.	Yield Strength, psi.	Elongation, Per Cent	Reduction of Area, Per Cent
11457	None	900	179,500	166,200	11.5	34.8
11486	None	900	175,200	167,200	11.5	32.5
11461	Aluminum	900	184,000	174,000	3.6	9.5
11480	Aluminum	900	174,900	164,900	6.8	13.5
11500	Aluminum	900	178,000	166,000	4.5	12.0

*Total residual aluminum by spectrograph.

FIG. 14—INCLUSIONS IN CENTRIFUGALLY-CAST ALLOY STEEL. TOP—HEAT 11457—NO ALUMINUM DEOXIDATION—TENSILE STRENGTH, 179,500 PSI.; ELONGATION, 11.5 PER CENT. BOTTOM—HEAT 11461—DEOXIDIZED WITH 0.029 PER CENT ALUMINUM—TENSILE STRENGTH, 184,000 PSI.; ELONGATION, 3.6 PER CENT. UNETCHED, MAGNIFICATION x100.

freeze. This gives true directional solidification, with consequent soundness and uniform properties. The directional freezing is accentuated by metal molds which remove heat more rapidly from the outside of the castings.

23. Most physical tests of cast steel are made on specimens machined from a keel block coupon[7] which is a perfectly fed test bar with truly controlled directional solidification. Test specimens machined from the wall of true centrifugal cylinders generally show physical properties which are equal to those obtained from the test bar under optimum conditions.

24. Structures found in centrifugally cast steel are not essentially different from those in any sound, well-fed steel casting. Figure 10 shows the as-cast and annealed structures of a 16-ft. long thick-walled, sand-mold, true, centrifugal casting. Figure 11 shows similar structures from a metal-mold, true, centrifugal casting. The metal mold casting has a finer as-cast grain structure.

QUALITY CONSIDERATIONS

25. There is little tendency toward pinhole porosity in true centrifugal castings. In most static sand castings, the formation of pinholes can be positively prevented only by the use of a powerful final deoxidizer, usually aluminum. True centrifugal castings in metal molds, in dry sand molds, or even in skin dried green sand molds are made free of pinholes without special

FIG. 15—SAME AS FIG. 14. HEAT 11560—DEOXIDIZED WITH 0.092 PER CENT ALUMINUM—TENSILE STRENGTH, 178,000 PSI.; ELONGATION, 4.5 PER CENT. UNETCHED, MAGNIFICATION x100.

deoxidation of the acid electric steel. This allows a latitude of deoxidation practice not commonly obtained.

26. It long has been recognized that aluminum deoxidation of acid steel tends to impair the ductility. Sims and Dahle[8] found that a small critical amount of aluminum was worse than a larger amount.

27. The loss of ductility by aluminum treatment is not of great significance in low or medium tensile strength ranges. As tensile strength is increased, the effect becomes more pronounced.

28. Opportunity to evaluate this effect statistically was afforded by the routine testing of some cylindrical parts for aircraft landing gear service. These parts are cast by the metal-mold, true, centrifugal process of alloy (4140) steel and are heat treated by normalizing, oil quenching, and tempering. Tensile tests are made for each heat and each test specimen is machined from the wall of an *actual centrifugal casting.* The required tensile strength varies from 150,000 psi. for some parts to 170,000 psi. minimum tensile strength for others. Figures 12 and 13 show typical microstructures of these castings in three conditions.

29. These heats normally are cast without any special deoxidation, other than that afforded by silicon and manganese. A few heats were made where most of the steel was to be poured in static green sand molds, and to these heats 2½ lb. per ton of aluminum was added at the tap. Table 1 shows typical comparative tests on standard 0.505-in. tensile test specimens from the heat-treated centrifugal castings with and without aluminum.

30. It is apparent from these examples that the steel with no special deoxidation is capable of giving quite satisfactory properties and that the aluminum addition seriously affects the ductility of the steel.

31. Figures 14 and 15 indicate that the cause of this effect is the inclusion type. It is interesting to note that the heat with higher residual aluminum has a somewhat less deleterious type of inclusion and a slightly higher ductility than the heat with lower residual aluminum.

32. Figure 16 shows tensile strength plotted against elongation for a number of heats. The tests plotted constitute all tests made on this steel over a consecutive period, including heats prior to and subesequent to the heats which were aluminum killed. Each point represents a single test and all tests, good or bad, are included. There are a number of variables which can cause a single test to show low ductility, but a high ductility test can only occur when all factors are correctly controlled. It is notable that none of the aluminum treated heats showed really superior ductility.

33. The above data is illustrative of but one of the numerous factors which affect the properties of cast steel. While the proper use of centrifugal methods helps to minimize many of the variables in steel casting, there are

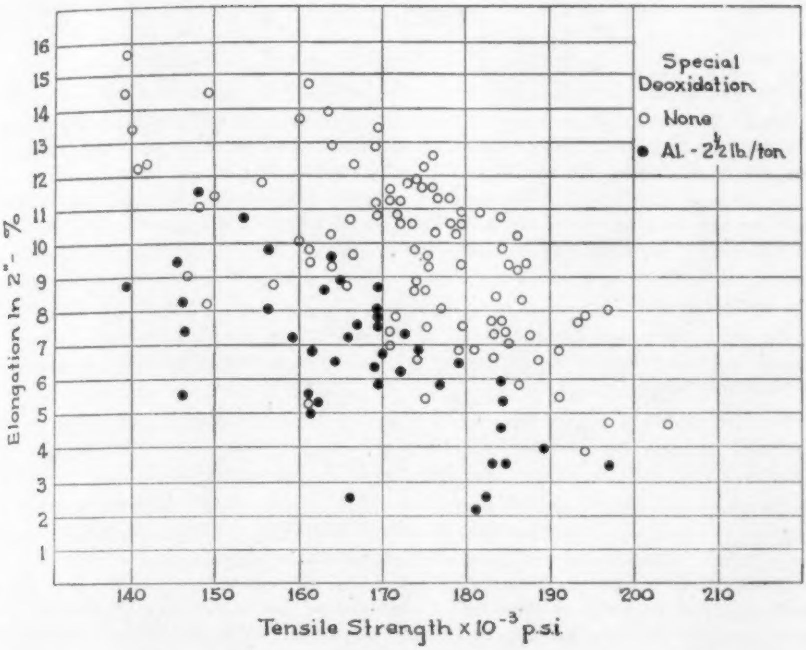


FIG. 16—INDIVIDUAL TENSILE TESTS OF HEAT TREATED ALLOY STEEL. ALL SPECIMENS MACHINED FROM METAL-MOLD CENTRIFUGAL CASTINGS.

always other factors which must be controlled carefully to obtain optimum properties. In many instances, steel parts can be produced by centrifugal casting methods which are physically equal, when tested in all directions, to steel parts formed by any other commercial method.

References

1. Briggs, C. W., *"The Development of Centrifugal Casting,"* IRON AGE, vol. 151, no. 19, pp. 53-55, May 13, 1943.

2. Cone, E. F., *"Centrifugally Cast Cylinder Barrels for Airplane Engines,"* METALS AND ALLOYS, vol. 16, no. 6, pp. 1062-1066, December, 1942.

3. McCarroll, R. H., *"Progress in Automotive Steel Castings,"* THE FOUNDRY, vol. 66, no. 10, pp. 30, 31, 72, 74, and 77, October, 1938.

4. Donoho, C. K., *"Centrifugally Cast Steel,"* IRON AGE, vol. 151, no. 13, pp. 52-58, April 1, 1943.

5. *"Casting Spinning Practice,"* IRON AGE, vol. 152, no. 23, pp. 54-59, December 2, 1943.

6. Wright, W. F., and Caine, J. B., *"Centrifuging After Filling the Mold,"* IRON AGE, vol. 151, no. 20, pp. 64-68, May 20, 1943.

7. Steel Founder's Society of America, STEEL CASTINGS HANDBOOK, First Edition (1941), p. 142.

8. Sims, C. E., and Dahle, F. B., *"Effect of Aluminum on the Properties of Medium Carbon Cast Steel,"* TRANSACTIONS, American Foundrymen's Association, vol. 46, p. 65 (1938).

DISCUSSION

Presiding: DR. A. E. SCHUH, U. S. Pipe & Foundry Co., Burlington, N. J.

Co-Chairman: J. B. CAINE, Sawbrook Steel Castings Co., Lockland, Ohio.

H. H. JOHNSON[1]: I am especially interested in the nomographic chart (Fig. 4) that Mr. Donoho presented. The relation of the speed to use with the centrifugal force of, say, 60 times gravity has introduced an idea that is new to us. How general is the application of that formula? In terms of spinning a car wheel weighing 500 lb. or more, with an outside diameter of 25 to 33 in. down to a bore of 6 in., perfectly solid all the way through, how would we calculate the centrifugal force required to give us the best speed? In other words, would the 60 times gravity factor be the speed which we would use for that kind of a job?

We quite agree that slipping, if the speed is too slow, is of importance. It has also been our finding that in casting against a metal mold, a slow speed will cause pitting of the surface of the casting.

We also feel that the spinning speed is of importance in determining the amount of chemical segregation. Mr. Donoho did not touch on that point. Does he have any ideas as to the relation between the spinning speed and segregation?

We noted with a great deal of interest the comments on the effect of aluminum on the physical properties of steels that have been centrifugally cast. We produced some heats, on a purely experimental basis, to which we added an aluminum that gave us poor sulphides. In our investigation we cross-sectioned some samples and gave them a deep acid etch, and we found that we had a condition of fissuring or hair-line cracks all the way through. We ascribed the condition to the aluminum, which had given us a weakened steel with the centrifugal pressure on top of that. We feel as Mr. Donoho does, that one of the chief merits of centrifugal casting is that we do not have to add aluminum or any deoxidizer, provided that the steel is well made, to get the best physical properties.

MR. DONOHO: The 75 times gravity speed, which has been used for years for cast iron pipe, was developed more or less empirically, and has been found to be a "favorable" speed. In 1922, Cammen* published a formula for calculating 75 g.

As to the 60 times gravity speed, it was also found empirically that metal molds will pick up the metal more readily than a sand mold, as Mr. Carrington also pointed out, and I believe that Nathan Janco** has advocated the figure of 60 times gravity as a useful value for metal mold horizontal centrifugal casting. Certainly, there is a favorable range of spinning speeds, and it would seem logical that the centrifugal force would govern where that range would fall. As for the car wheel casting mentioned, I should think that would, at least, be the best thing to try first.

As for the question about speeds and segregation, I do not believe that we have tried a sufficient number of speed variations to say that there would be more segregation with higher speed, or not. The pouring temperature probably would have a greater effect upon segregation than would spinning speed. If we have a very hot metal and allow it to freeze quite slowly, there is the maximum amount of segregation.

The comments on the effect of aluminum were quite interesting. I was a little hesitant about showing that. Some people, possibly, know how to add aluminum better than we do, and some people apparently can add aluminum to steel without hurting the properties seriously, but I merely showed that we did add it and what we got, and that is as far as I can go.

---

[1] National Malleable & Steel Castings Co., Sharon, Pa.

*Cammen, Leon, "*Centrifugal Casting,*" TRANSACTIONS, A.S.M.E., vol. 44, p. 284 (1922).

**Centrifugal Casting Machine Co., Tulsa, Okla.

CHAIRMAN SCHUH: On the matter of aluminum versus no aluminum, I would like to mention that our experience has been parallel to that of Mr. Donoho.

CO-CHAIRMAN CAINE: There is one point regarding aluminum versus no aluminum. It has been shown by a number of men, including Mr. Donoho, for both centrifugal and static practice, that silicon-killed steels will show better properties in the tension test than when we add aluminum. However, that does not seem to be true when we go into what are probably more important, the so-called "impact tests" that measure resistance to notch sensitivity. In this case, aluminum-killed steels, at least from the work of Sims and Dahle*, are definitely superior, and there are again indications that the so-called impact test can be correlated much better with the behavior of the casting in service than can the ordinary tension test. This point is mentioned because it may become important.

There is another point. Some of us who cast steel statically believe that we know how to add aluminum and obtain good properties, both impact and tension. When we get these high-strength steels that Mr. Donoho is talking about, 180,000-lb. steels cast centrifugally, it may be that there are different types of inclusions present than are found in the same steel cast statically, or with a soft steel cast centrifugally.

There is one other point in regard to centrifugal castings, especially centrifugal castings poured in sand. It has nothing to do with the metal but it is extremely important, and is the action of the steel against the sand. The amount of heat penetration into the sand when we spin a job is much greater than when we cast the same job statically, and there has been considerable trouble with adhering sand, which invariably shows up on inner surfaces and inside corners, not on the outer surfaces. We would expect it to occur where the centrifugal force is greatest, but it seems that it never does. If we cast a gear, for instance, it occurs around the center hub. It probably is due to turbulence, and can be eliminated. It is simply a matter of sand voids. We are simply accentuating mechanical penetration when we spin a casting, and get turbulence due to the spinning action.

MEMBER: What is the machining allowance for the outside and inside diameters of cast iron cylinder liners 8- or 10-in. diameter and one-inch finished wall thickness, cast centrifugally in metal molds?

F. G. CARRINGTON[2]: That type of sleeve is made in England and Germany a good deal, and they allow about 3/32-in. finish on each surface. That would be about 3/16-in. on the diameter for the bore and 3/16-in. on the diameter for turning.

M. J. GREGORY[3]: We cast about 15,000 liners a week, and we tried centrifugal casting with 3/32-in. finish, and it was a question as to whether the dross would get out. We discontinued the centrifugal casting and went to the horizontal sand casting. The 3/32-in. finish allowance is rather small, in my opinion. What is the inside machining allowance on the airplane engine cylinger that Mr. Donoho is making?

MR. DONOHO: The amount of metal that we have to take out is ¼-in. to the side on the inside, and we have gone a little higher than that, but ¼-in. is the normal figure. The cylinder barrel has to be absolutely perfect on the inside when it is finished, and it is a steel casting. In gray iron we might do a little better.

When cylinder liners or centrifugal castings of that sort are to be sold, they should be, if at all possible, rough machined at the foundry. Then the foundryman can deter-

*Sims, C. E., and Dahle, F. B., "*Comparative Quality of Converter Cast Steel*," PROCEEDINGS, A.S.T.M., vol. 42, pp. 532-555 (1942).

[2] Lynchburg Foundry Co., Lynchburg, Va.

[3] Caterpillar Tractor Co., Peoria, Ill

mine how much stock he has to take out and how much he has to put on and work it out in his own shop, instead of shipping rough castings and then hoping they will clean up satisfactorily.

CHAIRMAN SCHUH: What was your experience on this greater clean-up? Was that in a sand-lined mold or a metal mold?

MR. GREGORY: A dry sand mold. We found a ⅜-in. finish allowance necessary, and I believe that to be the general practice.

MR. CARRINGTON: The 3/32-in. finish that I mentioned was on sleeves cast in metal molds, and it was a very soft gray iron, very carefully skimmed before it was poured, and it was a type of metal that, if poured in an open sand casting, would give a very smooth surface, with no slag on it at all, and those sleeves were made by the metal-mold process in England. The figure that I gave for the German casting was given to me by the man that makes them.

CHAIRMAN SCHUH: In metal-lined molds, our experience would corroborate your dimensions for cleaning up.

H. G. SEAMANS[4]: We cast a few thousand liners each week and in the smaller liners, 5 and 6-in. inside diameter, 3/32-in. finish on the side is not uncommon. However, when we get into the 8, 9 and 10-in. inside diameter jobs, it generally goes up to 5/32 in. on the side.

MR. CAINE: As to these inside surface problems, we have been working with true centrifugals and probably have had the same trouble as others on this matter of clean-up on the inside diameter. When we first start casting centrifugally, we are going to leave ½-in. finish on the side. That does not mean that, when we have had some experience, we will always have to have a ½-in. finish. There is much work to be done on this matter of directional solidification, especially on the larger diameters. We desperately need now an insulating material that will prevent skin formation in the bores. This formation of a solid film of metal on the inside diameter before the section has solidified probably is the main reason now for excessive finish. When something is developed that will insulate the bore, we can protect this metal and have true directional solidification from the outside diameter to the inside diameter, then it will be simply a matter of accuracy in weighing the metal going into the mold, and I believe that the 3/32-in. finish then will be sufficient.

MR. GREGORY: There is a precaution to be observed when we get down to these scant finishes, and that is when we heat treat these castings by the reduction hardening method, especially when there is a microscopic examination by an inspection department.

CHAIRMAN SCHUH: We have had a demonstration of the fact that these later efforts in centrifugal casting have jumped from infancy almost to maturity. Wonderful work has been done, but much more work is needed. Some of the discussion today indicated the sort of work that is needed.

[4] Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich.

Spinning Speeds of Centrifugal Casting Machines

By F. G. Carrington*, Lynchburg, Va.

Abstract

The spinning speed, or revolutions per unit time, for a centrifugal mold is determined by a number of factors. These factors are; the direct effect of centrifugal force together with the force of gravity, the shape of the casting, details of machine design, and metallurgical characteristics. The fundamental differences of all these factors prevent their combined effects being determined except by experiment. Consequently, it has been necssary for the foundryman to try casting at various spinning speeds before arriving at the speed range best suited to his conditions. The approximate spinning speed at which the machine will operate should be known when it is being designed. Much data has been published on the spinning speeds used for castings, but to correlate such data, all the factors determining the speed must be taken into consideration. The purpose of this paper is to enumerate these factors and their individual effects. As casting conditions vary so much with the type of metals used, it may clarify the statements made to add that they are based largely on experience in casting ferrous metals.

Purposes of Spinning Molds

1. Centrifugal casting machines are used to give a number of entirely different results, depending on the castings being made. The benefits to structure might be the chief reason for making one casting in this way, the elimination of the central core might be the deciding factor for another, and the use of a permanent mold might be of major importance for a third. But all of these reasons for centrifugal casting will, in some way, be related to results more easily produced with the combined action of centrifugal force and gravity than under the action of gravity alone in a still mold.

2. The action of the centrifugal force alone is as if the metal were being pushed away radially from the axis of rotation, regardless of whether the axis is horizontal, vertical, or sloping. The magnitude of the force is dependent on the weight of the body, the radius of its rotary movement and its spinning speed. In centrifugal casting, the weight and radius of rotation are determined

*Lynchburg Foundry Co.

Note: This paper was presented at a Centrifugal Casting Symposium Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 28, 1944.

by the casting dimensions, leaving spinning speed as the only variable for the action of centrifugal force. As the force of gravity acts with a constant magnitude and in a vertical direction, any change in the combined action of these two forces must come through changing either the angle of the spinning axis to the horizontal or through changing the spinning speed.

3. The position of the spinning axis in casting machines usually is chosen to fit in with the type of casting being made. If the axis angle is kept constant during the casting operation, the spinning speed can be used to control the effects given to the metal by the combined forces.

Spinning Speed

4. Examining separately the results obtained by the use of centrifugal casting machines, it is found that most of these are not related to any particular spinning speed beyond a certain minimum. The use of permanent molds is facilitated, for instance, by the fact that the metal can be poured through the central cavity, and nothing is gained specifically in the use of such molds by increasing the spinning speed over that required for holding the metal in place. The metal structures obtained through the cooling effect of such molds and the elimination of the core are equally independent of the spinning speed used. For such results, the only reasons for spinning the mold are simply to cause the metal to flow into place and to remain there until solid.

Rate of Flow

5. The rate of flow, either upward in a vertical or sloping mold or longitudinal in a horizontal mold, can be speeded with an increase of centrifugal force acting on the metal. This becomes effective as the metal receives its rotary motion. So, the spinning speed requirements for the foregoing type of results are determined by the factors governing the rate of acceleration after the metal strikes the mold, the time interval during which solidification will not arrest the longitudinal flow, and the centrifugal force needed to hold the metal against the mold after it has flowed into place.

6. The holding of the metal in place and the shaping of the cavity are affected directly by the spinning speed and the spinning axis position. In horizontal molds, the cavity will be cylindrical, and there is a definite spinning speed for each cavity radius below which the centrifugal force can not prevent the metal falling as it spins through its upper arc. This establishes a minimum spinning speed to which the metal forming the inner surface must be accelerated. With this spinning speed for the surface, the metal will be held in place and the mold spinning speed must be adjusted to give this acceleration.

Mold Cavity

7. In sloping or vertical molds, the resultant from centrifugal force and

gravity is downward as well as radial and, following natural laws, the cavity section will be the shape of a parabola if the bottom end of the casting is solid. If the cavity extends through the casting, the shape of its section will be that of a length cut from a parabola with the radius length decreasing progressively from the top to the bottom.

8. As the spinning speed is increased, and for a given radius at the top, the cavity will extend deeper into the casting or, when the cavity extends entirely through the casting, the bottom radius length will become nearer that at the top. For the latter, the casting specifications usually limit the decrease in cavity radius from top to bottom, but no objection is made to this difference in radius length becoming smaller. Consequently, there is a minimum spinning speed for these castings, below which the bottom radius will be too short and above which the casting will be acceptable. As with the horizontal mold, the minimum speed to be considered for the cavity is not affected by the outside dimensions of the casting or the weight of the metal being cast.

9. Another effect of centrifugal force directly related to the spinning speed is the elimination of slag and gasses. But as this usually is carried to completion at the speed fixed by other considerations, it can be considered automatic in most cases.

FORMULAS FOR SPINNING SPEEDS AND PRESSURE

10. The mold spinning speed used in the casting operation will be at least the minimum speed for the cavity dimensions and often a speed much higher to give the required rates of acceleration and flow along the mold wall. Considering first the minimum speed for the cavity surface, this can be calculated with formulas that have been given before in discussions of centrifugal castings, and similar formulas throw further light on points of practical interest in machine design and operation.

11. Figure 1 shows the formulas applying to the following conditions:
Minimum spinning speed for cavity surface.
Influence of the sloped angle on cavity shape and spinning speed.
Cavity dimensions and volume for vertical and sloping molds..
Pressure on the mold end.
Radial pressure on the mold surface.
Bursting stress in the mold wall.
Pressure gradient across the metal section.

12. The units used are lb., revolutions per minute, slope in degree from the horizontal, and in. for casting dimensions. In the formula for pressure, the action of gravity is disregarded as this usually is negligible in comparison to that caused by centrifugal forces. These pressures are determined by the radii, the spinning speed, and the weight per cu. in. of the metal, and are the same regardless of the slope angle of the axis.

13. The general formula from which these are derived is one showing

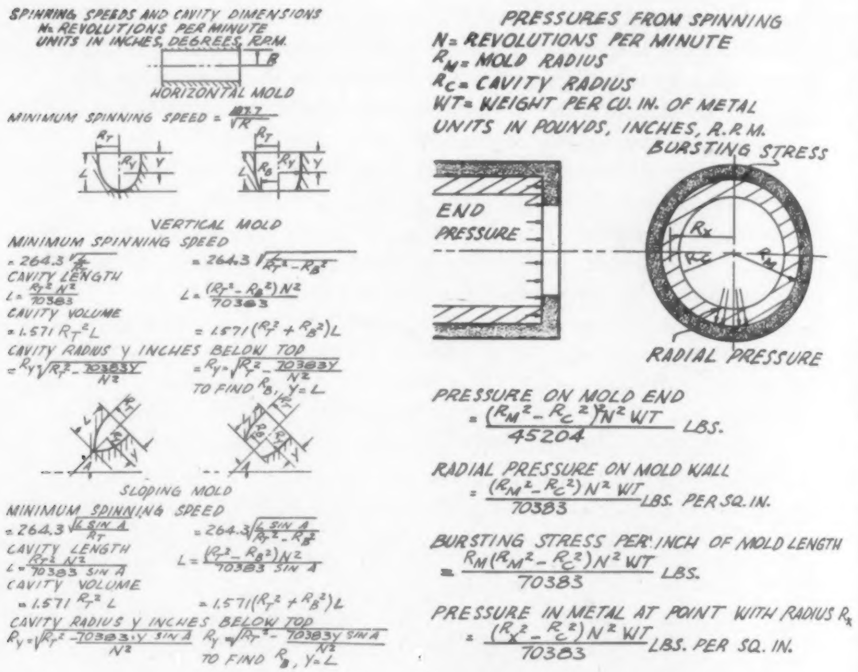


FIG. 1—FORMULAS FOR VARIOUS CONDITIONS OF CENTRIFUGAL CASTING.

the result of centrifugal force acting on liquids. Consequently, the figures obtained will be true only when the metal remains liquid long enough for the centrifugal force to give its complete effect. The cavity, for instance, can not take its shape if the metal begins to solidify before it has finished flowing along the mold wall. In the same way, formulas for the pressure on the mold wall and end assume the entire metal mass to be liquid and, if solidification begins before all the metal is poured, at least part of the calculated pressure will be resisted by the solidified metal shell. But, in spite of such errors, the calculations have value for machine design in showing the lowest spinning speed which need be considered and maximum pressure for which the mold must be reinforced.

14. As an example of the use of the formula, the calculations for a casting with the dimensions shown in Fig. 2 are as follows: The cavity length is 15 in. and the top radius 2 in. and the minimum bottom radius 1⅞ in. If cast vertically, the minimum spinning speed is

$$N = 263.4 \sqrt{\frac{L}{R_T^2 - R_B^2}} = 263.4 \sqrt{\frac{15}{4 - 3.516}} = 1472 \text{ rpm.}$$

15. This spinning speed in itself would not be prohibitive, but the pressure on the mold will be high where the 8-in. diameter collar is being formed.

Also, if a quick freezing metal like steel is being cast, a spinning speed 25 per cent over the minimum may be required to insure a sufficiently rapid flow up the mold wall. For such metal, a 30-degree slope might be available, which would give a minimum spinning speed of

$$N = 263.4\sqrt{\frac{\text{LSinA}}{R_T^2 - R_B^2}} = 263.4\sqrt{\frac{15 \times .5}{4 - 3.516}} = 1004 \text{ rpm.}$$

16. Again, using a 25 per cent increase over the minimum, or 1250 rpm. as the estimated casting speed, the calculations are:

(1) Bottom Radius

$$R_B = \sqrt{\frac{R_T^2 - 70383\ \text{LSinA}}{N^2}} = \sqrt{4 - \frac{70383 \times 1.5 \times .5}{1250^2}} = 1.938 \text{ in.}$$

(2) Pressure on Upper End

$$= \frac{(R_M^2 - R_C^2)^2\, N^2 Wt}{45204} = \frac{(16-4)^2 \times 1250^2 \times .28}{45204} = 1300 \text{ lb.}$$

(3) Radial Pressure on Mold Wall at 8-in. Collar

$$= \frac{(R_M^2 - R_C^2)\, N^2 Wt}{70383} = \frac{(16-4) \times 1250^2 \times .28}{70383} = 75.4 \text{ psi.}$$

(4) Pressure Gradient in Metal Section

$$= \frac{(R_X^2 - R_C^2)\, N^2 Wt}{70383} = \frac{(X^2 - 4) \times 1250^2 \times .28}{70383} = \begin{cases} \text{zero psi. when } X = 2 \text{ in.} \\ 14.2 \text{ psi. when } X = 2\tfrac{1}{2} \text{ in.} \\ 31.5 \text{ psi. when } X = 3 \text{ in.} \\ 52.1 \text{ psi. when } X = 3\tfrac{1}{2} \text{ in.} \\ 75.4 \text{ psi. when } X = 4 \text{ in.} \end{cases}$$

(5) Bursting Stress on Mold at 8-in. Collar, 1½-in. Long

$$= \frac{R_M (R_M^2 - R_C^2)\, N^2 Wt}{70383} = \frac{4\,(16-4) \times 1250^2 \times .28}{70383} = 301.6 \text{ lb. per in. of Mold Length}$$

$$301.6 \times 1\tfrac{1}{2} = 452.4 \text{ lb.}$$

17. From these figures, the cavity theoretically will have the dimensions shown while the metal is liquid. All of the dimensions will be then changed somewhat in the casting because of the shrinkage in the solid state, but if the proportionate difference between the top and bottom radii is greater than that calculated, it would indicate that solidification is beginning before the metal has been completely distributed and the spinning speed is too low.

Heat Transfer

18. The transfer of heat from the liquid mass will take place largely through the end and side-wall surfaces, which causes the central inner zone to solidify after the solidification of the exterior shell. Radial shrinkage in

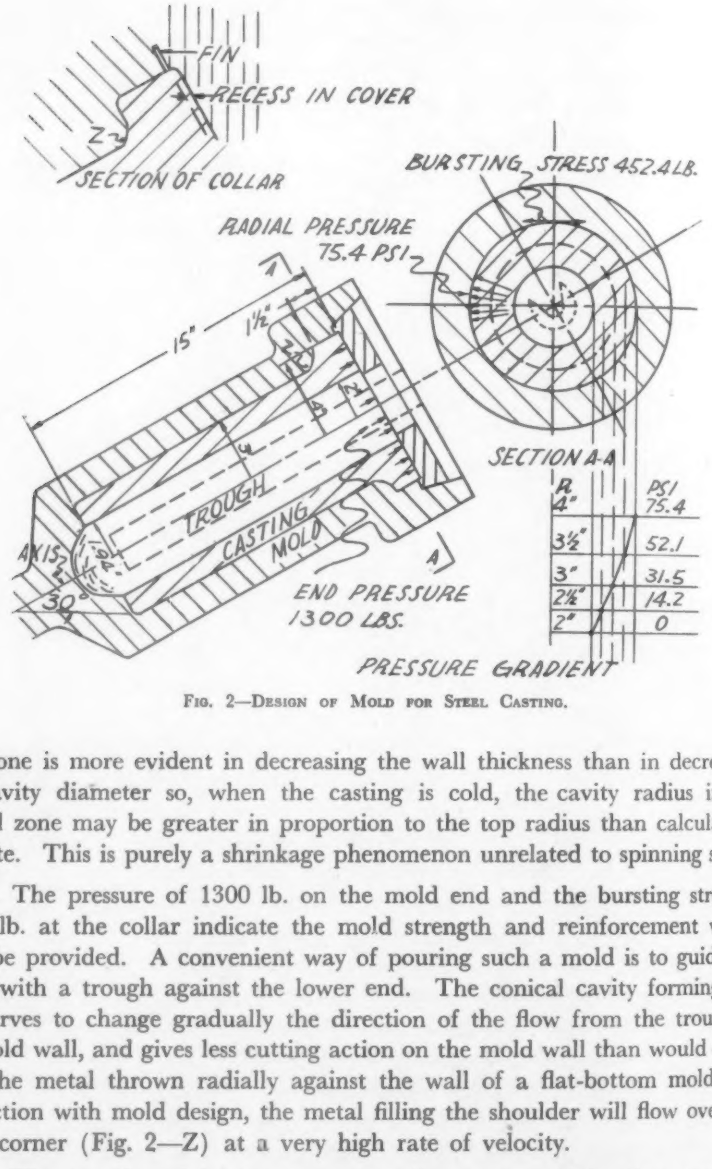


FIG. 2—DESIGN OF MOLD FOR STEEL CASTING.

that zone is more evident in decreasing the wall thickness than in decreasing the cavity diameter so, when the casting is cold, the cavity radius in the central zone may be greater in proportion to the top radius than calculations indicate. This is purely a shrinkage phenomenon unrelated to spinning speed.

19. The pressure of 1300 lb. on the mold end and the bursting stress of 452.4 lb. at the collar indicate the mold strength and reinforcement which must be provided. A convenient way of pouring such a mold is to guide the metal with a trough against the lower end. The conical cavity forming this end serves to change gradually the direction of the flow from the trough to the mold wall, and gives less cutting action on the mold wall than would occur with the metal thrown radially against the wall of a flat-bottom mold. In connection with mold design, the metal filling the shoulder will flow over the lower corner (Fig. 2—Z) at a very high rate of velocity.

20. The transfer of heat, or metal cooling and mold heating, increases with the velocity between the surfaces and would result in chilling the metal as well as locally overheating the mold at this point. This effect is lessened somewhat by rounding corners where flow takes place, with a radius as large as is permissible. Another point in mold design is that, due to the high pressure, the metal will form fins in extremely thin crevices such as occur at

the joints between molds and detachable covers. With such metal as cast iron, the fin will solidify and crack radially from shrinkage and, if the fin leads into a corner, the shrinkage on the fin will continue the crack into the casting body. This can be prevented by recessing the cover so that the joint leads into the side wall rather than the corner.

21. A chart of the pressure gradient across the mold wall sometimes is useful if segregation is being studied.

22. The comments in this paper are directed chiefly to the more common type of centrifugal casting, which has a central cavity and a spinning axis passing through the mold. Another type of casting is made with the spinning axis passing through a central pouring column which feeds the molds around it through radial gates. The purpose of spinning such molds is to force feed the castings. The pressure giving this result is the head of metal in the column plus the radial pressure from centrifugal force at points measured from the spinning axis, and these can be calculated with the pressure gradient formula by giving the inside radius *"R"* the value of zero.

FACTORS DETERMINING THE SPINNING SPEED FOR ACCELERATION AND FLOW

23. The spinning speed used in casting usually is fairly close to the calculated minimum speed for the cavity with vertical or steeply inclined molds, but with horizontal or slightly inclined molds, a wide difference will be found between the casting and the minimum speeds. This is due to the fact that, in the molds with the flatter spinning axes, the metal is delivered against the mold circumference and, while the metal striking the mold surface during the first revolution will be entrained by mold surface friction, all the succeeding metal will be accelerated by reason of the velocity of the liquid surface already spinning and the viscosity of the metal itself. This creates an appreciable slippage in the liquid strata between the mold and the interior surface which must be compensated for by increasing the mold speed.

24. In addition to speeding up the mold surface for slippage, the acceleration to the minimum speed must take place while traveling between the point of pouring and the center of the upper arc. The time for this becomes shorter as the speed is increased for a shorter radius. The combination of slippage and shortening of time for acceleration gives a constantly increasing ratio of the casting speed to the calculated minimum as the radius is reduced.

Flow in Vertical and Inclined Molds

25. In vertical or steeply inclined machines, the metal is delivered against the bottom of the mold and begins to move towards the mold circumference as soon as it begins to rotate. This prevents an increasing depth on the mold bottom as pouring is continued, and the sheet of metal is accelerated as it moves from the center to the mold wall. Besides giving much less slippage, the acceleration may be through the full circle or continued progressively for

several revolutions, instead of being limited to an arc as in the flat machines. From these differences, the factors affecting the rate of acceleration as compared to the minimum spinning speed are of considerable importance for the molds poured against the side wall and of little importance when pouring against the mold bottom.

26. The rate of longitudinal flow along the mold wall also may require a higher mold spinning speed than is calculated as the minimum for the cavity. The conditions affecting this are very similar to those governing the pouring of a flat plate in an open sand mold. A plate of very short length would be poured easily with any metal or mold material but, as it became longer or cooling began to cause the front edge of the metal to solidify before the mold was filled, faster pouring or hotter metal would be required.

27. In centrifugal casting, the pouring rate is limited by the amount of metal that can be accelerated continuously, and the pouring temperature has upper limits to meet other conditions. So, higher spinning speeds are sometimes required to hasten the flow. This is true both for molds poured against the side wall and for molds poured against the end, but the relationship of spinning speed to rate of flow is somewhat different, depending on whether the mold position requires pouring on the bottom or on the side wall. Because of the difference produced by the two areas of pouring, the factors determining the casting speed are considered separately for each.

METHODS OF POURING

Spout

28. The extremes of pouring methods for horizontal molds are illustrated in Figs. 3 and 4. In the first, the metal is poured through a spout in a short, thick stream and strikes in one end of the mold at the low point of its circumference. This creates a short, thick strata as the metal is first swept from under the stream, and a high degree of slippage because of the thickness

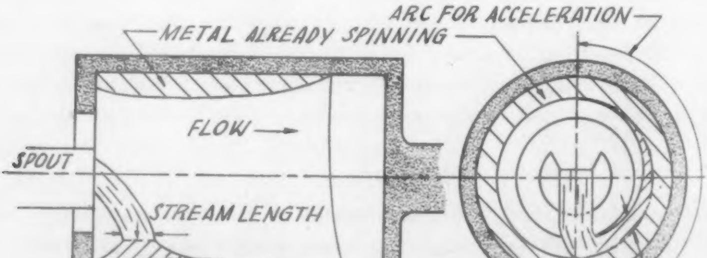


FIG. 3—DESIGN OF SPOUT POURED HORIZONTAL MOLD.

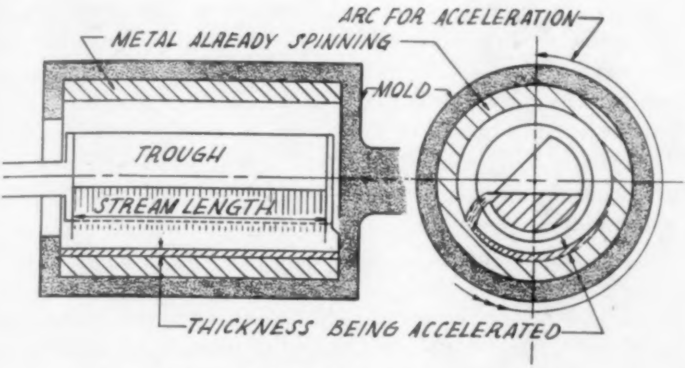


FIG. 4—DESIGN OF TROUGH POURED HORIZONTAL MOLD.

through which the acceleration must take place. The metal also must flow the full length of the mold, and this may further increase requirements for spinning speed if the tendency toward solidification is marked.

Trough

29. The trough shown in Fig. 4 contains the metal charge and is rotated to pour a long, thin stream against the downward moving side of the mold. As compared to the pouring method of Fig. 3, the stream is nearly the length of the mold and little longitudinal flow is required, the thinly applied metal is more easily accelerated, and the arc for acceleration is lengthened by the position at which the metal strikes the mold.

30. All of these factors would reduce the requirements for spinning speed, but the use of a trough of this kind is limited to slow freezing metals and to castings with cavities large enough to receive the trough. Its advantages are obtained partially by directing the stream through a spout towards the downward moving wall, or by using a small diameter trough which is fed from a metal container outside the mold as it is rotated.

31. Vertical molds usually are poured directly from a ladle through a hole in the top, and sloping molds can be poured in the same way until the slope is so flattened that the stream impinges on the side wall. This would create conditions for acceleration similar to those with the spout poured horizonal mold, and a trough is required to direct the metal against the bottom. The flattening of the slope angle is accompanied by reductions in minimum spinning speed, and this can be continued until the stream from the trough will fall to the mold wall. This again gives the conditions for acceleration of a horizontal mold.

32. Accelerating the spinning speed during pouring is sometimes employed. This may be done by pouring the metal into a still, or slowly revolving, mold and then bringing the mold to the casting speed before solidification begins.

This eliminates the cutting action and splashing of the metal when it first strikes the rapidly moving surface. To a lesser degree, the same results are obtained by starting the pouring with a speed based on the outer radius of the casting and increasing the speed as the cavity becomes smaller.

33. Progressive distribution of the metal, as in pipe machines, is another method of forming long, cylindrical cavities, but the complicated apparatus for synchronizing the trough movement with the rate of pouring prevents its general application.

POURING RATE

34. The rate at which the metal is poured governs somewhat the thickness of the metal being accelerated, and thus the increase in spinning speed to compensate for slippage. A faster pouring rate increases the rate of flow along the mold, though, so the results of a higher pouring rate are to increase the spinning speed needed for metal distribution. Increases in pouring rate over the lowest which gives a sufficient rate of longitudinal flow are much more noticeable with horizontal molds than with sloping and vertical molds.

METALLURGICAL CHARACTERISTICS

35. The metallurgical characteristics affecting spinning speed are the quickness of solidification or "life" of the metal and the temperature above the freezing point. To avoid cold shuts, the metal must be spread over the entire mold length in one continuous flow, similar to the flow across an open sand mold, and with quickly solidifying metals, either because of lack of "life" or of low temperature, the pouring rate and spinning speed must be increased correspondingly.

36. When longitudinal flow is not a problem, metals that solidify quickly may begin to do so while the casting is being poured. This solidifying lessens the thickness of liquid metal through which slippage can take place and the excess speed for acceleration can be reduced. A dull white cast iron, for instance, when poured so that no flow is required, would need about 15 per cent less speed than a hot gray iron similarly poured. From these conflicting results, quick freezing metals would require higher speeds in long vertical molds or in horizontal molds poured with a jet, but would require less speed if the vertical mold is short or if the horizontal machine is poured in a sheet requiring little flow.

MOLDS

37. The conductivity and temperature of the mold can speed or retard solidification. Their effect on spinning speed is very similar to that of the "life" and the temperature of the metal. With cold, high conductivity molds, the requirements for excess speed are increased if longitudinal flow is the determining factor, and decreased if the factor of accelertaion is the more

important. The surface of the mold must entrain the first metal poured against it, and should not be polished to an extent permitting it to slip under the metal.

CASTING DIMENSIONS

38. The casting thickness has no effect on calculations for minimum spinning speed. Very thin castings require a rapid longitudinal flow to spread the thin sheet of metal over the mold surface before it freezes, and a higher speed would be required than for thicker castings. For accelerating the metal, the slippage would be more pronounced with a deeper layer of molten metal and the mold spinning speed would be higher.

39. The length of the casting increases the time required for longitudinal flow, and a smaller cavity radius not only increases the mniimum spinning speed but also shortens the arc length in which the acceleration must take place. As a result, the speed required above the minimum must be greater for longer castings if quickly solidifying metal is used, and the ratio of casting speed to the minimum must be increased as the cavity radius becomes smaller.

MACHINE CONSTRUCTION

40. The effects of the spinning axis position on minimum spinning speeds and the factors controlling the acceleraiton and distribution of the metal have been discussed. In designing the machine, consideration must be given to such details as the removal of the castings and whether pouring from a ladle into a high speed vertical machine compensates for the difficulties with spouts and troughs on horizontal machines.

41. The design of the trough or spout also must depend on the fluidity of the metal and the diameter of the cavity, as well as the stream shape when it strikes the mold. So, the design of the machine can be changed to give lower spinning speed only when general operating conditions permit.

42. Regardless of the other details, vibration will increase materially the spinning speed required for accelerating the metal. This is due to the metal being entrained by surface contact, and, if this contact is made intermittent by vibration, the accelerating force can not be smoothly applied. This is evident especially in horizontal machines if the spinning speed enters the vibration range of the machine. Then, increasing the spinning speed also will increase the vibration, and the metal may continue to fall as it passes through the upper arc in spite of the increased speed. Vibration has a much greater effect in horizontal machines than in vertical machines, due to the greater relative importance of acceleration.

SEGREGATION

43. Variations in analysis occur across the wall of centrifugal castings, some

of which is due to separation, by centrifugal force, of constituents with densities different from that of the metal mass. This would account for the elimination of slag and gasses from the metal, or the higher than average content of graphite and manganese sulphide on the inner surface of iron castings. The same is true for the segregation that has been reported in alloys, such as lead and copper or copper and tin.

44. Other variations in analysis come from progressive solidification from the outer to the inner surface, produced by a condition similar to that causing analysis variations from the outside to the center of an ingot.

45. These analysis variations can be expected in centrifugal castings, but examination of a number of gray iron castings showed that the variations were the same at the high and low limits of spinning speed practical for the casting being made, and that the variation in analysis was never, in itself, sufficient to indicate a variation in physical properties.

CASTING DEFECTS DUE TO HIGH SPINNING SPEEDS

46. The mold wall surface, under all conditions, will be traveling with a rather high velocity, usually ranging from 1000 to 2000 ft. per min. The metal striking directly on the surface produces a marked cutting or erosive action and, if mold surface is broken, casting defects will result. Another type of defect is caused by a vibrating or rough mold splashing the inflowing stream and throwing globules of metal on the uncovered mold surface. The tendency toward both of these defects is lessened as the spinning speed is reduced.

47. A different type of defect associated with high spinning speed is the formation of cracks in the surface contacting the mold. In cast iron, these cracks occur with the quick freezing high shrinkage analysis and with mold conditions causing rapid cooling. The exact cause of these cracks can not be shown clearly, but the standard remedy for them is to reduce the spinning speed about 5 per cent, which usually is effective.

NUMERICAL VALUE OF FACTORS DETERMINING THE SPINNING SPEED

48. The numerical values of the factors being considered are indicated in Fig. 5. This shows the spinning speeds of gray and white cast iron when spun in a horizontal mold with different methods of pouring. The wall thicknesses of the metal were from 1/32 to 3/16 in. thick per in. of diameter, and the casting temperatures were 2200 to 2500° F.

49. The upper limit of the speed range (Fig. 5) is the spinning speed used for soft gray iron cast in sand molds and poured from a spout against the bottom of the mold circumference. The next line is for the same metal and mold, but the metal is directed against the downward moving side and the stream is elongated. The drop in spinning speed results from the faster acceleration with this stream shape. With the same metal and stream shape,

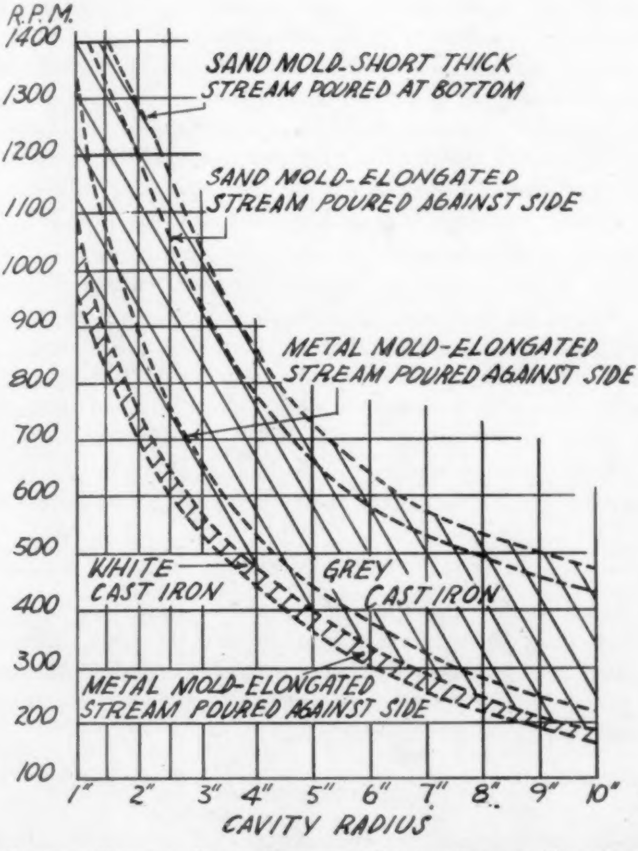


FIG. 5—NUMERICAL VALUES OF FACTORS DETERMINING SPINNING SPEEDS IN HORIZONTAL MOLDS.

but with a cast iron or steel mold at 400 to 800° F., average spinning speeds will drop to the next line.

50. This drop comes from the more rapid cooling and hastening of solidification so that only a portion of the wall thickness is liquid when the last metal is poured. This increases the acceleration through less depth of metal for slippage. Below this line is a zone for colder or less fluid metal, and then comes a zone for the quick freezing white cast iron with which the acceleration is even more rapid. The pouring conditions and stream shape used for the white iron castings make the acceleration much more important for spinning speed than the longitudinal distribution of the metal, in spite of its rapid solidification.

51. Steel seems to require about the same spinning speed as white cast iron for acceleration but, because of the high temperature and quickness with which it solidifies, increasing speeds are required to give longitudinal flow

as the mold length is increased. The observations reported are based on experience with steel castings of ½ to one-in. thickness.

52. Vertical or sloping molds poured against the mold bottom can be spun at the minimum rate with soft cast iron and sand molds due to slow solidification. Steel poured in a smoothly turning sand mold, about one ft. long, requires an increase of about 25 per cent over the minimum speed, and an additional 10 per cent or 15 per cent if the machine is vibrating badly.

53. In practice, variations in operating conditions can be met by adjusting the pouring rate and spinning speeds for mean conditions. The mold conductivity, type of metal, machine construction, and casting dimensions will be constant during the heat, and the principal variables will be the differences in metal temperature and analysis that are normal in a foundry.

54. While acceptable for casting quality, these normal changes in temperature and analysis may be sufficient to cause irregular metal thickness due to insufficient speed, or the surface defects which come with too high a spinning rate. Such variation usually can be met by changing the pouring rate and the spinning speed within limits of plus or minus 10 per cent of the mean.

CONCLUSION

55. As stated in the beginning, the comments that have been made are based on observation while casting in iron and steel foundries. However, from published data, it would seem that the spinning speeds for other metals are influenced in the same way by the conditions affecting the rates at which they can be accelerated or be given longitudinal flow.

ACKNOWLEDGMENT

56. Thanks are expressed to Professors O'Shaughnessey and Maher, of the Virginia Polytechnic Institute, for advice concerning the formulas.

DISCUSSION

Presiding: DR. A. E. SCHUH, U. S. Pipe & Foundry Co., Burlington, N. J.

Co-Chairman: J. B. CAINE, Sawbrook Steel Castings Co., Lockland, Ohio.

ERLE J. HUBBARD[1] *(written discussion):* The author should be complimented on the fine work presented in this paper. Because of our lack of experience and the scarcity of published information regarding details of centrifugal casting, we have had to experiment over a period of months and discover for ourselves the proper spinning speeds, pouring rate, etc.

We have been pouring a composition, calculated to produce a white cast iron, into horizontal spinning permanent molds. The outside diameter of the casting is 6½ in. and the length 14 in. A calculated weight of metal is poured to give a casting wall thickness of ⅝-in. We do not have any trouble when pouring the metal into a mold spinning at about 980 rpm., using a hand pouring ladle with a spout attached, the whole ladle looking somewhat like a coal scuttle. The metal hits the spinning mold wall about 2 in. from the end. Occasionally, we do get a few castings which show cold shut and accompanying lapping at the opposite end of the mold. However, this does not appear to be too serious as the removal of ⅛-in. of metal on the diameter usually remedies this condition.

We have had some difficulty in casting a cylinder 14 in. long, of the same outside diameter, but with a wall thickness of 1⅛ in. A permanent mold is used in this case also, and the metal introduced into the spinning mold in the same manner. Recently, we have encountered some longitudinal hot tears showing up on the outside of the casting, and were wondering if the author could offer any suggestions. The material is induction furnace melted and usually is poured at a temperature of 2850 to 2900° F. Could this condition be adjusted by changing the spinning speeds during pouring or immediately after the pouring had been completed? Does the author believe that this pouring temperature is too high? We try to maintain a mold temperature of 600 to 700° F. before pouring. Would a change in this temperature affect any of the critical conditions?

We are very well satisfied with the results obtained so far in our experiments and research into centrifugal casting, and feel that this method of casting offers some advantages over normal static means.

MR. CARRINGTON *(answer to Mr. Hubbard's written discussion):* Two types of longitudinal cracks have been observed by the author with casting conditions as described by Mr. Hubbard. With one type, rather short and shallow cracks occur in the pouring zone where the metal impinges on the mold, and these often can be eliminated by a reduction in spinning speed. The tendency for these cracks to form has also been lessened by changing the shape of the spout to give the metal stream a greater length along the mold axis.

A second type of crack is longer and deeper than the first, sometimes extending the length of the casting. These cracks occur when the casting has longitudinal streaks of different color, and can be attributed to the mold becoming oval when heated by the metal. Contact with the casting then is maintained only on the short axis of the oval mold, and the cracks result from the stresses produced by non-concentric cooling. The remedy for this type of crack is complete stress relieving of the mold before final machining.

It is assumed by the author that all cracks are caused directly by shrinkage stresses,

[1] Research Laboratory, Koppers Co., American Hammered Piston Ring Div., Baltimore, Md.

and the means suggested for eliminating them are mechanical ways for preventing the stresses becoming localized. From this point of view, the cracking would increase with greater temperature differences across the section of metal being cast, so lower casting temperatures would be desirable.

The thermal effect of the mold on cracking would depend on its heat absorption capacity, and this would be influenced by its mass as well as by its temperature. Assuming the mold wall to be cast iron or steel and to be two to three times the thickness of the casting being made, the mold temperature does not seem excessive.

CHAIRMAN SCHUH: Mr. Carrington has brought out rather well in his paper that, within the range of the spinning speeds conventionally used, it is the rate of freezing of the metal which will primarily determine the amount of segregation of molecularly dispersed components; the slower the freezing the greater the possibility for segregation of such components. Gross visible impurities, which usually have an appreciably lower specific gravity than the liquid metal, are swept to the zones of lower centrifugal pressure. The higher the centrifugal force applied, the more effective is this cleansing action.

It is highly desirable to arrive at a commonly accepted nomenclature with regard to the mathematical expressions used for defining the magnitude of the centrifugal force employed. At the present time, such expressions as "number of times gravity," "peripheral mold speed" and "pressure against interior mold wall" are used. Of these, I have a definite preference for the latter.

On the matter of preferred spinning speeds, especially in the case of true centrifugal castings, mathematics can guide us only to a certain point. By necessity, we must assume that we are dealing with a constant-viscosity liquid. On the basis of this assumption, definite relationships between rotational speed, diameter of casting, wall thickness of casting, and specific gravity of the liquid exist.

Actually, however, we are dealing with a liquid which is rapidly changing in viscosity over a wide range. It is this condition which lends so much importance to such practical factors as pouring rate, the frictional character of the mold surface, the degree of superheat in the molten metal, and the speed with which heat is transferred from the molten metal to the mold. These latter factors do not as yet lend themselves to rigorous mathematical analysis.

Precision Casting by the Investment Molding Process

By Robert Neiman*, Louisville, Kentucky

Abstract

The author shows how the precision casting process by the investment method fills a need for producing accurate castings of an intricate nature for War work. The historical basis is given briefly and developed more fully in its dental use which serves as the basis for the precision casting process. The physical principles of compensating shrinkages and expansions are given along with the properties of pattern materials, investments, and casting alloys. Detailed information is given for producing precision castings from the original blueprint stage to the final inspection and gaging. The principles involved are correlated with practice in the steps involving dies, wax patterns, investments, mold "burn-out," and casting by both pressure and centrifugal methods. Data, apparatus descriptions, and precision possible are given in graphical and illustrated form.

OUR country's war production program has emphasized the need for a method of producing precision metal parts of intricate shape from alloys difficult to machine. Such a method has been in use for several decades for the production of dental and medical appliances and for some cast jewelry.

It has been adapted successfully in the production of many vital aircraft and armament parts. This method is known as the "investment process" and involves the use of wax patterns. It also is known as the "lost wax" process (French cire perdu).

The investment process is used in comparatively few plants to date, these being principally dental or jewelry manufacturers or their licensees. There is a wealth of literature on the dental technique but practically none on the actual principles and technique of commercial investment casting. The purpose of this paper is to tell what the investment process is, how it is carried out, and when, where, and why its use is indicated.

Before beginning the detailed study of the physical principles of precision casting and their practical application, it is perhaps advisable to predict that this method will find its place in post-war time alongside the recognized metal forming and shaping operations, including sand casting, die casting, hot forming and forging, cold drawing, stamping, and machining.

Other important new methods include plaster casting and powder metallurgy. Each method has its advantages for certain applications. It is hoped that precision casting will be given an equal chance, through sponsored and continued research, by those concerns capable of doing so.

---

*Director of Research, Whip-Mix Corp., Inc., Chemicast Div.

Note: This paper was presented at a Centrifugal Casting Symposium Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 27, 1944.

HISTORICAL

Dentistry

Wax patterns were used in the production of artistic castings in the 16th century by Benvenuto Cellini. Like other of his contemporaries, artistic countrymen such as Raphael and Stradivarius, he kept his method secret. The "lost wax" process, however, was rediscovered in 1897 by a dentist, B. F. Philbrook of Iowa.[1]* Real recognition for discovery usually is given to W. H. Taggart.[2]

Dr. Taggart gave emphasis to his invention by introducing a complete casting outfit and necessary materials to the dental profession. Although materials and methods have been improved greatly and perfected, the original process is still essentially the same.

The dentist must produce a single gold casting that will be an exact replica of the missing tooth structure, his object is very small and irregular; he can not enlarge his wax pattern (by the shrink rule), yet his finished casting must be accurate to better than a thousandth of an inch.

After the dentist prepares the wax pattern, the rest of the investment process can be carried out by a comparatively inexperienced assistant. That such an accurate process can be so simple and comparatively foolproof is a tribute to the constant research being carried out by dentists, dental schools, the American Dental Association Research Fellowship at the Nation Bureau of Standards, and the dental manufacturers.

Jewelry Manufacture

It is little wonder that this ingenious process should be adapted to a related art, the casting of precious alloys for jewelry. The jeweler is not so demanding in dimensional accuracy but does require intricate shapes with smooth surfaces and minute detail, with the further requirement of many similar castings from one master.

War Production

With the advent of this war, especially with the entrance of the United States, the dental and jewelry industries had the opportunity of utilizing their science and art to help build the mighty "Arsenal of Democracy."

It has been demonstrated by the New York Jewelry Crafts Association[3] that the centrifugal casting of small ordnance and aircraft parts can be done with a resultant saving of large quantities of strategic materials, thousands of man hours, and countless machine tools. Above all, it reduced tool-up time from months to a matter of days.

Another example of a known use of the investment process by dental methods, is the casting of turbo-supercharger buckets from chromium-cobalt-tungsten alloys of the type used in dental and medical appliances. These alloys are extremely corrosion resistant and have high hot strength, but are difficult to forge or machine. These are being precision cast by several companies who utilize centrifugal as well as pressure casting methods.[4, 5]

The company with which the author is associated formed a division to produce precision cast aircraft and armament parts by the

*Superior numbers refer to bibliography at the end of the paper.

investment process, utilizing centrifugal as well as air pressure methods.

Typical methods used by precision casting manufacturers will be used throughout this paper to illustrate the various principles of the investment process.

DENTAL METHODS

Precision casting by the investment process using wax patterns (or disappearing patterns) is essentially the same as dental casting but on a larger scale. The dentist makes inlays weighing 1/10 oz., the jeweler makes ½-oz. rings and the precision caster has made castings weighing one lb. with 5-lb. castings in the offing. Casting sizes can be increased far beyond this with larger equipment and continually improved materials. The precision caster looks with awe at the foundryman pouring ton castings. The foundryman looks with amazement at the comparatively tiny precision casting. Foundry practices vary quite a bit in the two industries, but there are many points of similarity. A mutual understanding of these practices should aid the foundryman in his search for greater accuracy and quality, and the precision caster in his desire for quantity and increased casting size.

Procedure in Making an Inlay

The basic fundamentals of precision casting are found in the dental method of producing a cast inlay restoration. A step-by-step description of the method follows. It must be remembered, in the description, that the work of producing and carving the wax pattern is done on the tooth in the patient's mouth at a temperature of 95 to 98° F. Steps A to E, Fig. 1, are performed at that temperature. After the wax pattern is removed from the patient's mouth, it is handled in the laboratory at room temperature (appr. 75° F., av.) until cemented in place on the tooth in the mouth. Figure 1 illustrates and describes the various operations in making a gold inlay.

PHYSICAL PRINCIPLES OF SHRINKAGE COMPENSATION IN PRECISION CASTING

The practical method having been described, it is now advisable to enter into a discussion of the physical principles that serve as the basis of all processes for producing accurate castings in investment. The dental process for producing accurate cast gold inlays or fillings will be used as an example throughout the following discussion because it is well established on a scientific basis through years of study in commercial laboratories, universities and, especially, at the Bureau of Standards. These principles should be well understood as they are the basis of casting any alloy in any size in any quantity.

In any casting process, the goal is a casting of a given size. With this as a given or fiducial point, we must determine all shrinkages in the process, sum them up and compensate for these negative quantities by an equal summation of expansion or positive quantities.

Foundry Methods of Calculation of Shrinkage

The foundryman has one shrinkage with which to contend, namely, the casting shrinkage of the metal. For example, if a certain brass

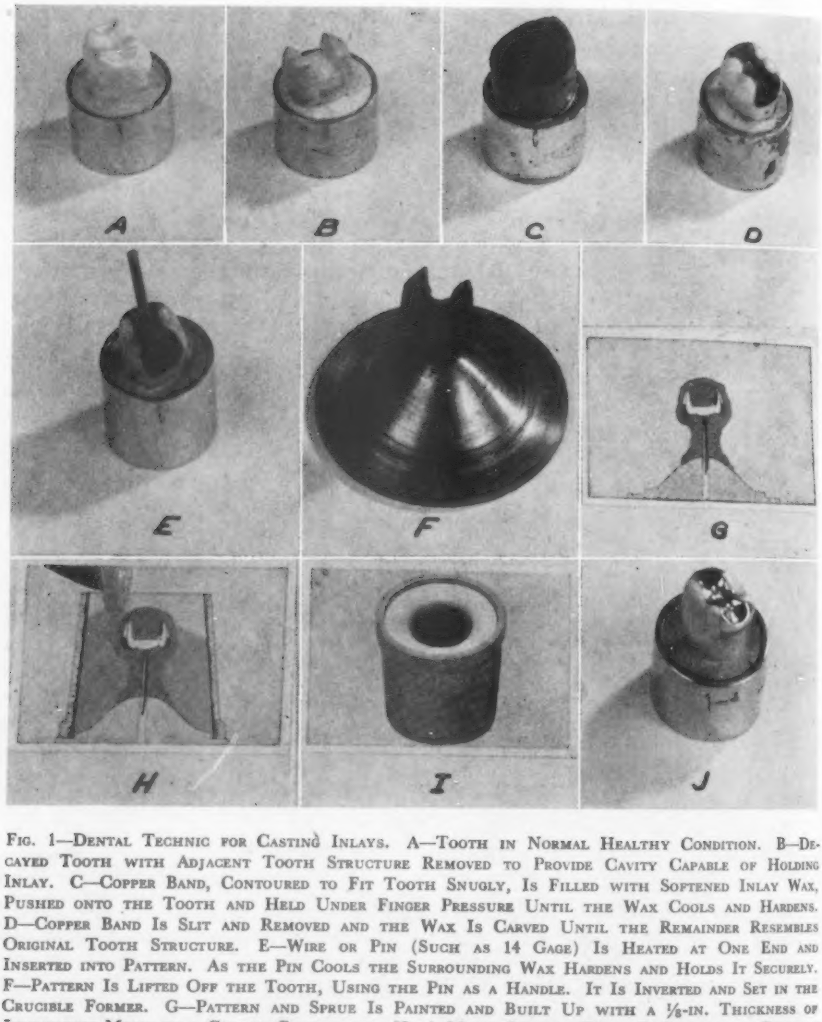


Fig. 1—Dental Technic for Casting Inlays. A—Tooth in Normal Healthy Condition. B—Decayed Tooth with Adjacent Tooth Structure Removed to Provide Cavity Capable of Holding Inlay. C—Copper Band, Contoured to Fit Tooth Snugly, Is Filled with Softened Inlay Wax, Pushed onto the Tooth and Held Under Finger Pressure Until the Wax Cools and Hardens. D—Copper Band Is Slit and Removed and the Wax Is Carved Until the Remainder Resembles Original Tooth Structure. E—Wire or Pin (Such as 14 Gage) Is Heated at One End and Inserted into Pattern. As the Pin Cools the Surrounding Wax Hardens and Holds It Securely. F—Pattern Is Lifted Off the Tooth, Using the Pin as a Handle. It Is Inverted and Set in the Crucible Former. G—Pattern and Sprue Is Painted and Built Up with a ⅛-in. Thickness of Investment Mixed to a Creamy Consistency. H—A Metal Ring or Flask Is Set on the Crucible Former Surrounding the Painted Pattern. The Ring Is Filled with Additional Investment. After the Investment Sets ½ Hr. the Crucible Former Is Removed and the Wire Pin Pulled Out, Leaving a Sprue Hole Leading to the Pattern. I—The Ring or Flask Is Placed in Furnace for ½ to One Hr. and Heated to Dull Red Heat (1200° F., 650° C.). The Wax Pattern Volatilizes and Disappears, Leaving a Hollow Pattern Chamber. The Flask Is Set in a Casting Machine, Metal Placed in the Crucible, Molten and Forced into Pattern Chamber Through Sprue Hole. J—Mold Is Plunged in Water, Investment Removed and Sprue Cut Off. Remaining Casting Is Ready to be Cemented in Tooth.

shrinks ¼ in. per ft., the sand founder will use the shrink rule and add ¼ in. per linear ft. to his patterns. Thus when the pattern is removed from the sand, it leaves a mold cavity ¼ in. per linear ft. larger than the finished object. Metal is poured into the cavity, whereupon it solidifies, cools and shrinks ¼ in. per ft. so that the finished casting is the size required.

When a foundryman makes a match plate, he first produces a master pattern to which a "double shrink" is added. One shrinkage allowance covers that from the single master to the match plate. The second shrinkage allowance is from the match plate to the practical casting. For example, using a brass with a shrinkage of 7/32 in. per ft., or 1.82 per cent, double shrinkage would be 3.64 per cent.

Precision Investment Method

Wax Shrinkage. The dentist is confronted with different conditions, including a double shrinkage and a double expansion, but again careful balancing of the ledger will produce the desired results. First, the shrinkages will be considered. Since the pattern that forms the mold cavity is wax, its thermal changes affect the mold size. The wax is adapted to the tooth cavity (which is our fiducial point) at mouth temperature which is very nearly 95° F.; the pattern is then handled at room temperature, usually 75° F. (average year around in dental offices) so that it cools 20° F. From an expansion (and contraction) curve of a typical pattern wax (Fig. 2), it is seen that the shrinkage from 95° F. to 75° F. is 0.35 per cent minus 0.10 per cent or 0.25 per cent.

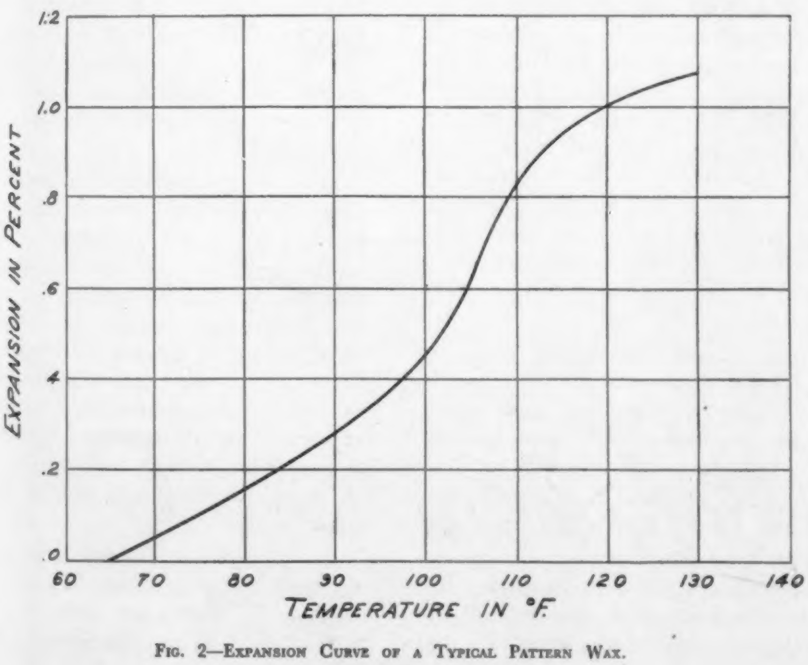


Fig. 2—Expansion Curve of a Typical Pattern Wax.

Metal Casting Shrinkage. The other shrinkage is the casting shrinkage of the gold alloy. This has been determined to be 1.25 per cent. This figure was determined, along with many other physical properties of dental materials, in the classical work of R. L. Coleman.[6]

The total shrinkage is thus 0.25 per cent plus 1.25 per cent, or 1.50 per cent.

Compensating Expansions. This may be compensated for by the following modes for expanding the mold cavity:

(1) Heating the wax pattern.
(2) Setting expansion of the investment.
(3) Thermal expansion of the investment.

No. 1 was used before the advent of high-expanding investments. It was carried out by covering the wax pattern with an investment mixed with hot water. Thus, if the pattern was covered in investment at 115° F., the wax would expand 0.5 per cent. This took place before the investment set hard. Since another 1.0 per cent for complete compensation is needed, an investment with 0.3 per cent setting expansion and 0.7 per cent thermal expansion would be used.

At present, the dentist uses, for example, an investment with 0.3 per cent setting expansion and which will expand thermally upon heating to 1200 to 1300° F. (649 to 704° C.), an additional 1.2 per cent. Thus, 1.2 per cent plus 0.3 per cent equals 1.5 per cent.

Obviously, all dentists do not use the same wax and same type of investment nor work in a 75° F. room, nor are all inlays the same size and shape. The dentist must study the conditions and compensate accordingly. Simple yet accurate means for doing this are furnished by the investment manufacturer.

MATERIALS

The principal materials and equipment used by the dentist, jeweler and precision caster are as follows:

(1) Waxes

A dental inlay wax must become pliable at about 110 to 125° F. (43 to 52° C.) so that it can be softened and applied to the tooth structure without undue discomfort. It must be quite hard at mouth temperature so that it will not distort upon removal. It should be easily carved without flaking and be of a dark color so as to be easily differentiated from tooth structure. It must volatilize and burn away without leaving any appreciable ash. Details, test methods and specifications were developed at the Bureau of Standards.[7]

Inlay waxes consist of a paraffin base with proper working characteristics controlled by compounding with one or more of the following: beeswax, carnauba, candellila, ceresin, damar and stearin, as well as new synthetic waxes. Coleman[6] gives the following formula: paraffin 60 per cent, carnauba 25 per cent, ceresin 10 per cent, refined beeswax 5 per cent. Others will be found in Appendix I at the end of the paper

Waxes have unusually high coefficients of expansion. They will change in dimension quite a bit with a small change in temperature

(Fig. 2). Wax patterns should be invested as soon as possible after removal from the tooth as they are highly subject to distortion, losing accurate shape even in a few hours. This is variously explained as being due to elasticity and the tendency of the wax to return to its former shape before being stressed and forced into position. Waxes consist of a mixture of crystalline and amorphous materials and are thus subject to plastic flow (even under their own weight).

Some of the latest developments in pattern materials include the use of plastics and low fusing metals.[23] These are indicated where extreme accuracy is necessary. The cost is greater than that of wax, but even this is being overcome.

(2) Investment

The dictionary defines this word as "the act of surrounding, that which invests or clothes; dress, vestment." In casting work, investment means the material that surrounds or covers the patterns. It is the mold-forming material and the counterpart of the foundryman's sand.

Investments vary widely in composition, but all of them consist of a refractory aggregate (such as powdered silica) and a binder (such as plaster of paris) which will form a creamy fluid mixture when mixed with water. This will flow or can be vibrated into place and will set or harden to a hard, cementitious mass. Typical investment formulae are given in Appendix II at the end of this paper.

In the foundry, the sand molds almost invariably are used at room temperature; therefore, no expansion nor contraction due to heating or cooling takes place. With investments, the conditions are different. Expansion takes place during the setting or hardening and is known as setting expansion.

Investments also expand during their heating to volatilize the encased or invested patterns, and will contract if they are cooled before casting. These expansions and contractions control the cavity size and shape and must be controlled accurately and their values accurately measured. It should be noted that if the investment expands, all cavities (pattern chambers) therein expand in the same proportion. Likewise if the investment contracts, all cavities therein will contract. For example: if the investment has a thermal expansion of 1.0%, the investment and all cavities therein will expand 0.010 ins. per inch (regardless of investment mold or cavity size or shape. The following section will develop the properties of investments.

Setting Time. Investments should form a plastic mass of the consistency of thick cream and maintain such for about 3 to 5 min. to permit painting and investing of the pattern. Setting time may be varied to suit the need.

Strength. The crushing strengths of investments (dry, at room temperature) are from 1000 to 3000 psi. and rarely cause trouble on this score. Hot strengths are about 400 psi.

Fineness. Since the cast inlay can not be ground or polished on the side to fit the cavity lest the perfect fit be destroyed, the cast surface must be extremely smooth. Bureau of Standards Specifications[15] call for a fineness of investment

materials such that all shall pass a no. 30 sieve, 95 per cent shall pass a no. 100 sieve, 85 per cent through a 325 sieve. The average particle size is about 500 mesh, and is many times finer than the finest foundry sand. Commercial dental investments are being used for precision casting work. Modifications are made to suit the user's process.

Permeability. Since the metal is forced into the mold under pressure (10 to 30 psi.), the investment can be dense and thus present a hard, dense, smooth surface. The permeability of the mold at 1200° F. (649° C.) or casting temperature has never been successfully measured, but from measurements at room temperature it has about 1/10 the permeability of an average sand. Permeability is controlled by investment particle size and shape, and by the amount of gaging water used. More water increases permeability.

Chemical Properties. The investment should not contain any ingredients that will react with the molten casting alloy to cause undue gas evolution, oxidation, or other chemical reaction. These would destroy the physical properties of the casting and the surface finish would be unsightly as well as too rough to meet accurate specifications. The investment formulas given in Appendix II show examples of the wide variety of ingredients used to give desired chemical as well as physical characteristics to investments.

Setting Expansion. Plaster of paris, the most universal investment binder (except for casting high-fusing ferrous and cobalt-chromium alloys), expands on setting and imparts this property to investments. Plaster expands from 0.2 to 0.5 per cent and investments do likewise. The three curves in Fig. 3 show the setting expansion of a typical investment (Type 6—Appendix II) under various conditions. In the curve marked "dry," Fig. 3, which shows the setting expansion in air, note that the maximum expansion is reached in about one hr. and that there is no appreciable subsequent change even in 24 hr.

Plaster of paris (and its investments) will expand even more if permitted to set in contact with or immersed in water. This is known as hygroscopic expansion. The setting expansion can be increased by lining the investing ring with a thin strip of wet asbestos paper before placing the investment therein. The curve marked "moist," Fig. 3, shows the effect of a single asbestos liner. A double thickness of asbestos will permit even greater infusion of moisture and will increase the expansion another 0.1 per cent. The curve marked "wet" shows the setting expansion for complete immersion under water 7 min. after investing. If placed under water sooner, there will be greater expansion.

There is thus quite a choice in setting expansion so that one may vary the expansion of the same investment merely by a choice of the moisture conditions during the setting. Rigid control in preparation of investments is necessary to insure reproducible expansion from time to time under the various possible conditions.

Thermal Expansion. It is fortunate that the heating of an investment mold to a dull red heat

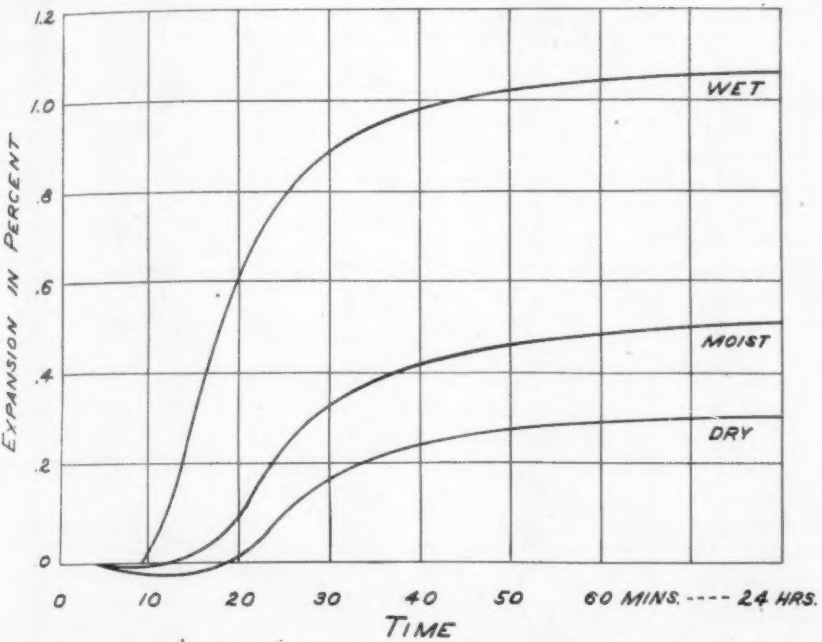


Fig. 3—Setting Expansion Curves of a Typical Investment Under Various Conditions.

(1200 to 1300° F., 649 to 704° C.) serves three necessary purposes: (1) it dissipates or volatilizes the wax pattern and burns away any carbonaceous residues, (2) it provides a mold hot enough to prevent premature freezing of the casting alloy in this section, and (3) it expands the mold so as to help compensate for wax and metal shrinkages.

Investments consist essentially of silica and plaster. Figure 4 shows the thermal expansion of four forms of silica. It is to be noted that the form most universally used, namely, quartz or sand, has a thermal expansion of 1.5 per cent, and most of this occurs near its inversion temperature at approximately 1063° F. (573° C.). This inversion involves a crystal change from low quartz to high quartz. Cristobalite, another phase of silica, has an even greater expansion and occurs at a lower temperature, namely, approximately 450° F. (232° C.). Tridymite also has high expansion and inverts twice at an even lower temperature. Fused quartz has the lowest expansion of any commonly occurring material.

Plaster is unusual in that it shrinks tremendously upon heating. In fact, it shrinks about as much as silica expands. Gypsum is calcium sulphate with 21 per cent of chemically combined water. When heated to about 400° F. (204° C.), 15 per cent water is driven off and plaster of paris is formed. When plaster of paris is mixed with water, it takes up 15 per cent of water and returns to gypsum. Upon heating, set plaster (gypsum) again loses

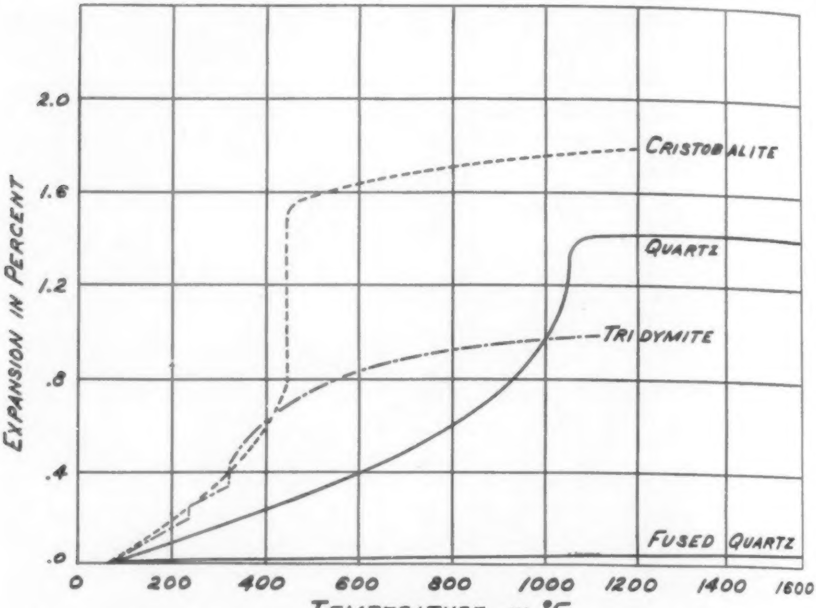


FIG. 4—THERMAL EXPANSION OF FOUR FORMS OF SILICA. NOTE THAT MOST OF QUARTZ EXPANSION OCCURS NEAR ITS INVERSION TEMPERATURE (APPROXIMATELY 1063° F.)

water and changes to plaster, or hemihydrate ($CaSO_4 . \frac{1}{2} H_2O$). This changes to soluble anhydrite at about 500° F. (260° C.) and finally to dead-burned gypsum ($CaSO_4$) at 600 to 850° F. (315 to 455° C.). The latter change, and its accompanying shrinkage, causes cracking of plaster molds during heating and drying, and is the principal obstacle to the more widespread use of plaster molds for casting metal. It is to be noted in Fig. 5 that the thermal expansion of plaster of paris varies considerable depending upon the ratio of water to plaster of paris. Curve 1, Fig. 5, shows the expansion and contraction when using 49 parts water to 100 parts plaster, and curve 2 shows the same when using less water, namely 37 parts water per 100 parts of plaster. These curves are based on the use of a special form of plaster known as alpha gypsum.[21] This material has a normal pouring consistency of 40 parts of water to 100 parts of powder. Ordinary plaster of paris requires 60 parts of water to 100 parts of powder, and has an even greater shrinkage.

To overcome the tremendous shrinkage of plaster, investments contain a larger proportion of silica, 60 to 80 per cent, and a minimum proportion of plaster, 20 to 40 per cent. In addition, certain agents are added to improve the expansion. Typical types of investments and formulae are given in Appendix II. Figure 6 shows the thermal expansion of three typical investments, types 1, 5 and 6. Type 1 is a typical investment base material. Types 5 and 6 have various additions and changes made to increase the expansion.

It is usual dental practice to heat the investment to about 1200 to 1300° F. (649 to 704° C.) and cast into the mold at this temperature so as to make use of the greatest expansion possible. A hot mold is also necessary to the dentist to insure the metal reaching all fine interstices and thin sections of the pattern. For larger molds and with larger sprue holes, the mold need not be so hot, in fact, it will enhance quicker cooling of the metal if the mold is cooler. Curve 1, Fig. 7, shows the thermal expansion of Type 1 investment on heating, and curves 2 and 3 the shrinkage upon cooling. It is to be noted that, as the mold is cooled, it will shrink to a point much lower than that reached at the same temperature during the heating cycle. The shrinkage will vary, depending upon the temperature at which cooling is started. Curve 2 shows the cooling shrinkage from the maximum temperature of 1400° F. (760° C.), and the curve 3 shows the cooling shrinkage when held at a constant temperature of 500° F. (260° C.) for about 2 hr. and then cooled. Therefore, it is necessary to determine expansion and contraction values for the particular investment under the exact temperature and time conditions under which it is used in practice to insure having correct values for use in compensation calculations. The maximum temperature usually is that required to completely dissipate the pattern material. Dental castings almost invariably are made in molds at their maximum temperature to utilize the maximum expansion. Cast-

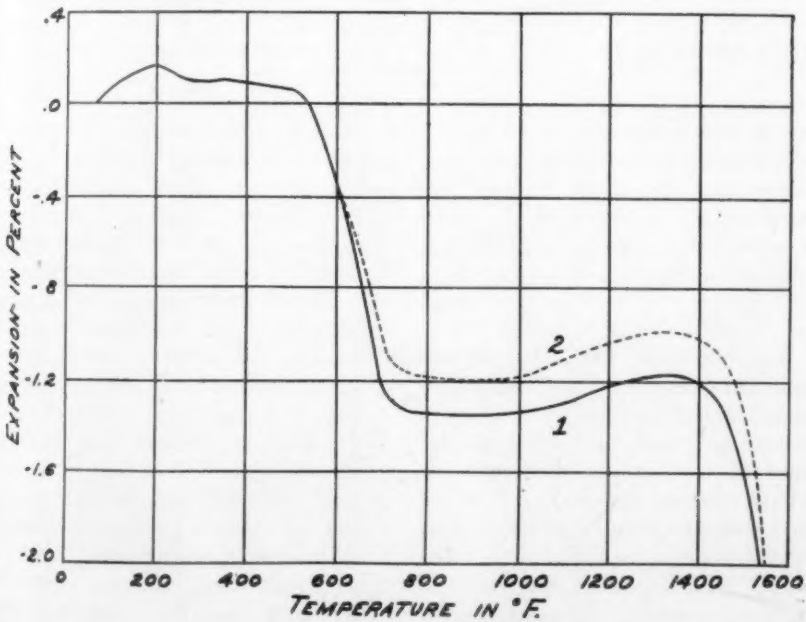


Fig. 5—Thermal Expansion of Plaster of Paris. Curve 1—49 Parts Water to 100 Parts Plaster. Curve 2—37 Parts Water to 100 Parts Plaster.

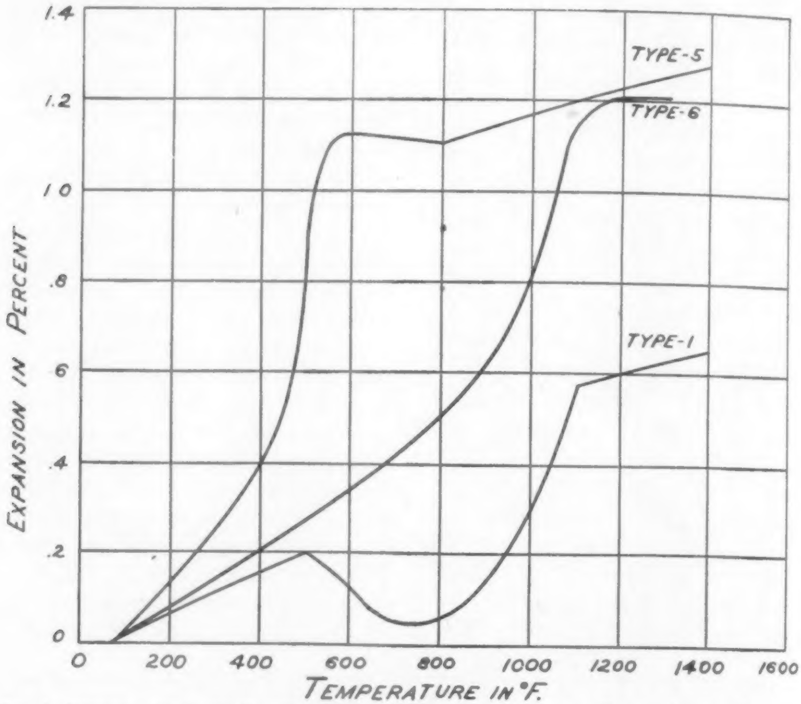


FIG. 6—THERMAL EXPANSION CURVES FOR THREE TYPICAL INVESTMENTS. CURVES ARE FOR INVESTMENT TYPES 1, 5 AND 6 OF APPENDIX II.

ing in cool molds is possible when necessitated by metallurgical considerations. However, cooling the mold invites cracking of the mold due to the added strain of a high negative coefficient of expansion.

(3) *Casting Alloys*

Types of Alloys Castable. At one time or another, practically all metals and alloys have been cast in investments with at least some degree of success. Aluminum casts well, as do zinc alloys. It is believed that magnesium also will cast successfully when proper care is exercised. However, the principal field of application is in copper-base alloys, stainless steels and chromium alloys. The casting of low-alloy and carbon steel is as yet impossible in plaster-containing investment, and not too successful in more refractory investments. However, this is the goal of all precision casters, and is looked forward to with optimism.

Many precision-cast brass parts were previously machined from free-turning yellow brass, tobin bronze, naval brass, and others available as extruded shapes or bar stock. It is necessary to match the standing specifications with alloys in the "as-cast" state. The physical properties of alloys cast in investment molds are approximately the same as sand cast. Brasses containing 58 to 65 per cent copper, 0.1 to 1.0 per cent aluminum and the remainder substantially zinc, can be

cast with tensile strengths in excess of 50,000 psi. and elongation of over 20 per cent. Tensile strengths as high as 110,000 psi. and elongation of 10 to 40 per cent are possible with manganese bronzes. For specific requirements, aluminum bronzes and silicon bronzes can be cast successfully.

To date, alloys containing over 0.5 per cent lead and high in copper have not provided smooth surfaces. Further work in investments is expected to overcome this difficulty. This is true of investments containing plaster. Stainless alloys, such as cobalt-chromium-molybdenum and similar alloys of the "stellite" types, as well as stainless steel, are successfully cast in special investments, such as types 9 and 10 of Appendix II.

Nature of Casting Shrinkage. Alloys go through three decreases in volume during casting[6]:

(1) Contraction of liquid from casting temperature to freezing point.

(2) Contraction of alloy due to change of phase from liquid to solid at constant freezing temperature.

(3) Contraction of solid alloy from freezing point to room temperature.

Pure gold is used as an example because accurate contraction data are available, although data for item 1 have not been determined

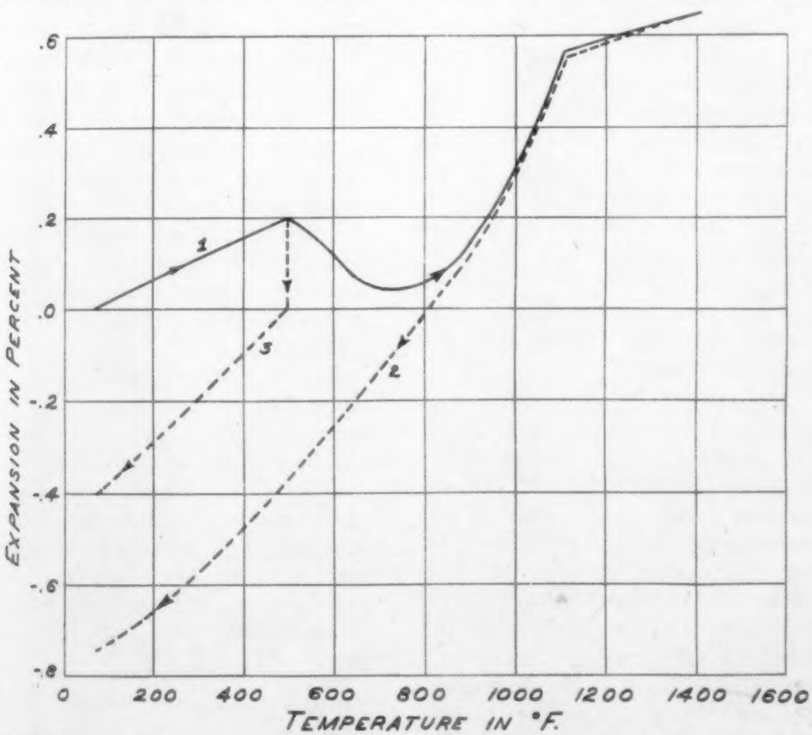


Fig. 7—Thermal Expansion and Shrinkage Curves of Type 1 Investment. Curve 1—Expansion on Heating. Curves 2 and 3—Shrinkage on Cooling from Different Temperatures.

reliably. Item 2 is given as 1.46 per cent. Item 3 is 1.76 per cent. Under favorable conditions all of the contraction, except in the solid state, is compensated for by the addition of more liquid from the crucible. The contraction of pure gold in the solid state is 1.76 per cent, and of the alloy 90 per cent gold, 10 per cent copper is 1.62 per cent. The actual casting shrinkage of the latter is 1.25 per cent in investment molds, and does not vary appreciably due to changes in casting temperature, mold temperature or pressure.

This also is true of the aluminum-copper alloy containing 95 per cent aluminum, 5 per cent copper when cast in sand[6] where a casting shrinkage of 1.64 per cent was found. The contraction of pure aluminum from its freezing point to room temperature is 1.95 per cent by extrapolation of the values given in reference 12. The contraction of 95 per cent aluminum, 5 per cent copper alloy is known to be but slightly less than that of pure aluminum, so that the use of a value of 1.9 per cent is safe. Again, the casting shrinkage is lower than the normal shrinkage.

The contraction of brass from its freezing point is not easily found, but extrapolation of various curves from 600° C. (1112° F.) to the freezing point gives values of approximately 2.5 per cent for a 60 per cent copper—40 per cent zinc alloy. The casting shrinkage of this type alloy is ¼ in. per ft. (2.08 per cent) for sand castings, and a similar value is found in the investment process. Here again the casting shrinkage is less than normal shrinkage.

The difference between normal contraction and casting shrinkage may be due to one or more of the following[6]:

(1) There may be sufficient friction or interlocking of the first thin shell of alloy to solidify, to permit its being heated and stretched (it is still comparatively soft) by the bulk of the still molten metal in the center.

(2) Some of the alloy may cool and solidify before the metal in the crucible freezes and thus some of the cooling shrinkage is compensated for by new molten metal.

It is the author's belief that considerable work has yet to be done to learn more about this phenomenon. Some workers in the dental field have shown no difference in contraction due to difference in casting size or shape; in practice the dentist requires more expansion for larger multiple surface inlays. Many measurements made on larger precision castings (brass) show variations in actual shrinkage. It is not believed that this is due to variation in casting shrinkage of the alloy, but to other factors, the nature of which is still unexplainable. As more data become available on castings of various sizes and shapes, and more is known on the effect of investment in resisting metal shrinkage, a more comprehensive understanding of this subject will be forthcoming.

PATTERNS

Master Pattern

The production of a precision casting begins with an actual piece

of the desired shape and size, if it is in production, or a blueprint of a new part to be made. If a part is available, it often is most time saving to make a preliminary die and make test-castings. In this way, various methods of sprueing, etc., are tested and the best way determined. Most helpful is the opportunity to determine shrinkages and the necessary means and amount of compensation.

Obviously, on a new piece, the beginning is the blueprint. Here, as usual, consultation between customer and precision caster will produce the best and most economical results. Experience to date has shown that in most cases the object or part can be redesigned to give added features which were originally desired, but which had to be omitted for various practical reasons, such as limitations of coring in sand casting or costly machining operations.

Shrinkage Calculation. With a given design and specifications, shrinkages and expansions are calculated. Supposing, for example, that a certain dimension is given as 1.000 in., plus or minus 0.003 in. (Fig. 8*A*). From practice, we have learned that our wax shrinks 1.0 per cent; i.e., it is adapted to a warm mold and upon cooling to room temperature it shrinks 1.0 per cent. A brass, containing essentially 65 per cent copper and 35 per cent zinc, is to be used which has a patternmaker's shrinkage of 7/32 in. per ft., or 1.80 per cent. These shrinkages total (1.0 per cent and 1.80 per cent) 2.80 per cent.

Compensation Calculations. The chosen investment has a setting expansion of 0.3 per cent and a thermal expansion of 1.0 per cent at 1200° F. (649° C.), giving a total of 1.3 per cent. There still is a difference of (2.80 minus 1.3) 1.5 per cent (shrinkage). If a dentist were making the job and he needed but one casting, he would resort to placing the pattern in a warm investment or letting the investment set under water to achieve a hygroscopic expansion of 1.5 per cent. Since perhaps 10,000 pieces are needed, the foundryman's method of enlarging the pattern is the best resort. However, it is necessary to produce but one master, and it is well to make it accurate and smooth, as it will produce all of the patterns. A 1.5 per cent increase in pattern size is needed. Therefore, 0.015 in. is added to the 1.000 in. and produces a master pattern 1.015 in. in size. This usually can be held to a tolerance of 0.001 in., and often to plus or minus 0.0005 in. or better. These calculations are shown in Table 1.

Metal Die

Alloy. The die needs only to resist molten wax, seldom over 200° F. (93° C.) and under pressures of several thousand psi. If the object is not too complicated, the die may be machined from steel, brass, or even aluminum or zinc, and all or part of it can be machined to size without need of a master. A steel die has shown no wear in the production of 107,000 patterns.

Where the design is complicated and a master is needed, it is necessary to resort to the use of low-melting alloys, such as 50 per cent bismuth, 32.2 per cent lead and 17.8 per cent tin, or 60 per cent tin and 40 per cent bismuth. These alloys have no shrinkage or expansion if properly balanced in compo-

Table 1

COMPENSATION CALCULATIONS

		Per Cent
Dental		
(A) Shrinkages		
Wax pattern shrinkage (95 to 75° F.)		0.25
Casting shrinkage of gold		1.25
	Total	1.50
(B) Expansions		
Setting expansion of investment (Type 6)		0.30
Thermal expansion of investment (at 1200° F.)		1.20
	Total	1.50
Total shrinkages (1.50 per cent) = Total expansions (1.50 per cent)		
Precision Casting		
(A) Shrinkages		
Wax pattern shrinkage		1.00
Casting shrinkage of brass		1.80
	Total	2.80
(B) Expansions		
Setting expansion of investment		0.30
Thermal expansion of investment (at 1200° F.)		1.00
	Total	1.30

Shrinkages—expansions = 2.8 per cent—1.3 per cent = 1.5 per cent. Therefore, master patterns should be enlarged 1.5 per cent.

Total shrinkages (2.8 per cent) = total expansions (2.8 per cent).

sition. Bismuth expands on cooling, and if 40 to 50 per cent is used, the alloy as a whole will be neutral in casting shrinkage.

Die Production (Fig. 8). A matrix or holder is made of convenient size, two pieces of steel (1 and 1′) 6x4x½ in. are cut away in the center leaving a rectangular opening (2) 4x3x½ in. They are held in relative position with pins (3) similar to flasks holding cope and drag. Part *B,* Fig. 8, shows a cross section through the center along the 6-in. dimension.

The opening in one half of the holder is filled with plastic clay (4), Part *B,* and the master pattern (5) (1.015 in.) is pushed into the clay to the desired parting line. The excess clay is trimmed away to give a fairly smooth surface.

The upper half matrix (1′) is placed on top of (1) and secured with pins (3). Fusible metal is heated to about 50° F. above its fusing point and poured quickly over the master pattern and forms the upper mold half *C* (6).

After cooling, the entire assembly is inverted, the clay (4) is removed and fusible metal is poured into the space. An excess of fusible metal is used and then planed off even with the finished die. The master is then removed and the halves put together. It should be noted that (7) *C* will form the entrance sprue of the wax.

The example shows a very simple pattern: obviously, an intricate pattern would be made in similar manner but with a die made in a number of sections, similar to an intricate sand casting made in an assembly of cores. For example, a hole may be made in the pattern by setting a pin in the die at the time it is poured. This is shown as (8) in Fig. 8, *B, C* and *D.*

Pattern Production. The metal die is assembled and lubricated with oil or special lubricants. A wax gun (9), Fig. 8 *D,* is placed over the mold and properly clamped. Wax is kept a little above its melting point by a suitable heating element wound around (9) *D*. Wax is forced into the pattern chamber by pushing piston (10) downward by means of a handle (11) pivoted at (12).

To speed up production, it is possible to put several similar cavities in a die and thus produce several wax patterns at once. The die can be mounted in an assembly so that opening and closing the die is done mechanically. Many controls, such as timing, automatic injection, etc., are included in some machines. These are almost a necessity to insure reproducible accuracy.

As soon as the pattern has solidified, the mold *D* is separated and the pattern is removed. The pattern had been adapted in a warm die, and upon cooling it will shrink. This will be one per cent, for example. The finished pattern, as shown at *E* in Fig. 8, will have its critical dimensions one per cent smaller than the die chamber. It is now 1.005 in. long.

Pattern Assembly. Figure 9 *A* shows a typical pattern assembly. The base is a crucible former (1) into which a sprue forming rod (2) is inserted. Patterns *a, b* and *c* are held in recesses in the rod by means

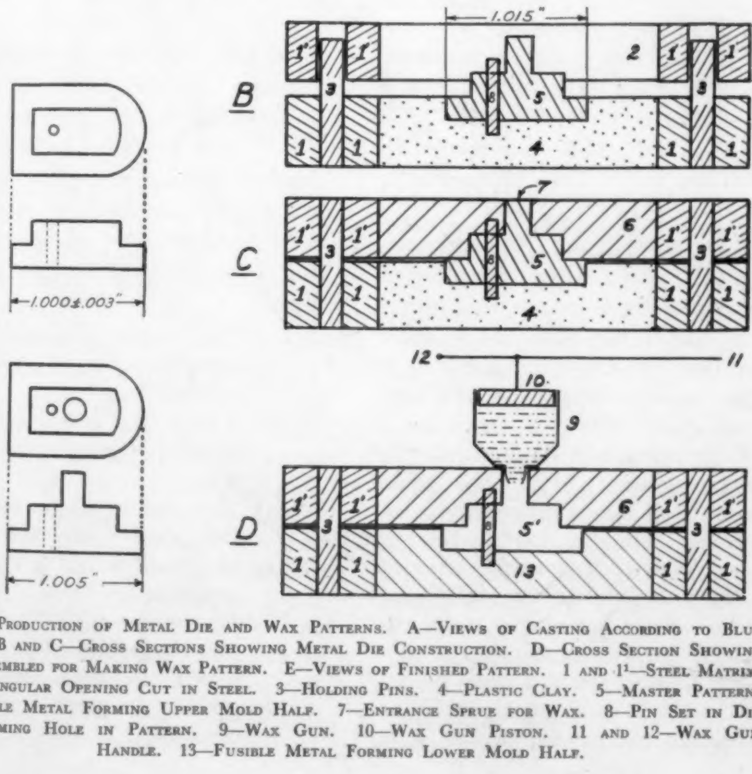


FIG. 8—PRODUCTION OF METAL DIE AND WAX PATTERNS. A—VIEWS OF CASTING ACCORDING TO BLUE PRINT. B AND C—CROSS SECTIONS SHOWING METAL DIE CONSTRUCTION. D—CROSS SECTION SHOWING DIE ASSEMBLED FOR MAKING WAX PATTERN. E—VIEWS OF FINISHED PATTERN. 1 AND 1¹—STEEL MATRIX. 2—RECTANGULAR OPENING CUT IN STEEL. 3—HOLDING PINS. 4—PLASTIC CLAY. 5—MASTER PATTERN. 6—FUSIBLE METAL FORMING UPPER MOLD HALF. 7—ENTRANCE SPRUE FOR WAX. 8—PIN SET IN DIE FOR FORMING HOLE IN PATTERN. 9—WAX GUN. 10—WAX GUN PISTON. 11 AND 12—WAX GUN HANDLE. 13—FUSIBLE METAL FORMING LOWER MOLD HALF.

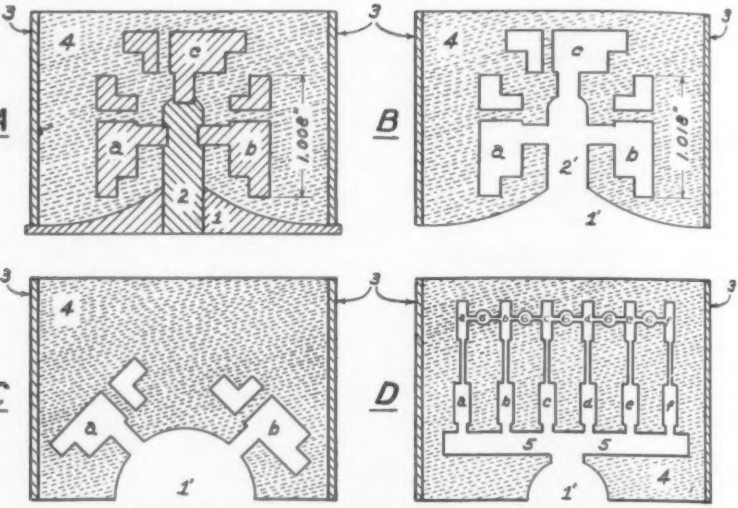


FIG. 9—PATTERN MOUNTING, INVESTING AND DISSIPATING. A AND B—TYPICAL PATTERN ASSEMBLY. A—BEFORE BURN-OUT. B—AFTER BURN-OUT. C—TWO-PATTERN ASSEMBLY. D—TYPE OF PATTERN ASSEMBLY CONFIGURATION ESPECIALLY ADAPTED TO THIN-SECTIONED CASTINGS. 1—CRUCIBLE FORMER. 1¹—CRUCIBLE. 2—SPRUE FORMING ROD. 2¹—SPRUE. 3—METAL RING FORMING FLASK. 4—INVESTMENT. 5—MAIN GATE. 6—BLIND RISERS. "A-B-C-D-E-F" PATTERN CAVITIES.

of an adhesive, such as hot wax. The metal ring (3) is placed on the crucible former. It forms the flask into which investment is poured to form the mold. The investment is shown as (4).

Pattern Mounting. For example, Fig. 9, *C* and *D* show several other possible methods for assembling patterns. In *C,* two patterns are shown but this could be increased to a larger number dependant upon size. As in *A* and *B,* Fig. 9, the crucible (1′) is formed by removal of the crucible former (1). The mold shown at *D* uses a different type of assembly configuration[4]. This is especially desirable for thin-sectioned castings to be cast of high-fusing alloys. Note that molten metal enters the crucible or main sprue (1′) and is then spread in a main runner (5), whence it flows through the gates into the pattern cavities *a, b, c, d, e* and *f.* The far end of the castings are connected by small gates to shrink bobs or "blind risers" (6). There are many other possible configurations for mounting patterns. The methods of mounting used are dependant on several factors, among which are the following:

(1) The economy to placing as many patterns as possible in one mold.
(2) The ability of the metal to fill all patterns before solidifying.
(3) The ability of the metal to freeze selectively, first in the pattern and then in the gates or sprues.
(4) Ease with which the patterns may be mounted and with which the gates and risers can be removed from the castings.

INVESTING

Water is measured and poured into a mixer, investment material is weighed and gradually sifted into the water into which it is incorporated by a hand spatula or knife. The components then are mixed in an electrically driven spatulator for a predetermined interval of time. The mixed investment is poured from the mixing bowl directly into the ring or flask, entirely covering the patterns and is leveled with the top of the ring. The mold assembly is placed on a vibrator during investing so as to assure the patterns being covered with investment and entrapped air driven upward. The investment is shown as (4) in Fig. 9, *A, B, C* and *D*. It is mandatory that the patterns be assembled so as to permit air to be displaced upward by the investment and not entrapped in "blind corners." The investment expands 0.3 per cent on setting and the mold cavity is 1.008 in. (Fig. 9 *A*).

MOLD BURNOUT

After the investment has set (about 30 min.), the crucible former (1), Fig. 9 *A*, is removed and the pin (2) is heated with a small torch. This melts the wax on its surface and the pin can be pulled out. The mold is handled sprue hole down to prevent the entrance of dirt and to let the wax run downward as the mold is heated. The molds are placed in gas or electric furnaces and heated slowly to the desired temperature, usually between 1000 and 1300° F. (538 to 705° C.). This temperature is sufficient to volatilize and burn away the wax. Thus the disappearing wax patterns leave mold cavities into which the molten metal can be cast. The molds should be heated from one to 4 hr., as investments are low heat conductors and too rapid heating (or cooling) will cause uneven expansion (or contraction), resulting in cracked molds.

To recover the wax, it is advisable to give the molds a prolonged preheating at a low temperature, 200 to 300° F. (94 to 149° C.). This melts the wax and lets it flow into receptacles where it is collected. The temperature must be kept comparatively low to prevent decomposition of the wax. When the patterns have insufficient bulk to make reclaiming economical, the mold may be placed in the furnace directly and the wax dissipated.

Wax goes through several stages in being dissipated. First it softens and then melts. Some of the molten wax is absorbed by the porous investment. Like most organic materials, it begins to decompose on heating; some volatilizes and the remainder carbonizes. Continued heating burns away the carbon at a rate that increases with temperature and time. The investment used expands 1.0 per cent on heating, producing a mold cavity that measures 1.018 in. (Fig. 9 *B*).

CASTING

(1) Pressure Methods

Dental Type Casting Machine[18]. For the small type of casting made in dentistry, pressure casting is used on an equal footing with centrifugal casting. A typical casting machine of this type is shown in Fig. 10, *A*. The machine base (1) has a self contained pressure tank (2). Air is compressed therein manually by piston pump (3), or compressed air

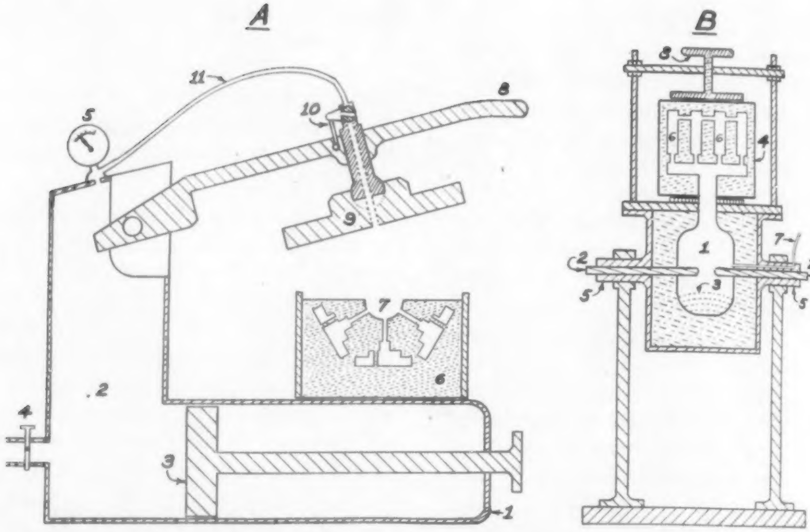


FIG. 10—A—LINE SKETCH OF PRESSURE TYPE CASTING MACHINE. 1—MACHINE BASE. 2—AIR PRESSURE TANK. 3—PISTON PUMP. 4—COMPRESSED AIR VALVE. 5—PRESSURE GAGE. 6—MOLD. 7—CRUCIBLE. 8—HANDLE. 9—HEAD. 10—AIR VALVE MECHANISM. 11—AIR HOSE. B—ARC FURNACE PRESSURE CASTING MACHINE. 1—ENCLOSED ARC FURNACE. 2—ELECTRODES. 3—MOLTEN METAL. 4—MOLD. 5—TRUNNIONS FOR INVERTING ASSEMBLY. 6—MOLD CAVITY. 7—AIR PRESSURE LINE. 8—MOLD CLAMP.

may be secured from an outside source through valve (4). Pressure is indicated on gage (5). The mold or flask is placed at (6), metal is placed at (7) to be melted by a torch (or molten metal may be poured) directly on the investment. The concave upper surface of the investment acts as a crucible. By pressing down the handle (8) the head (9) is lowered onto the mold, at which time valve mechanism (10) opens and permits compressed air from the base tank to pass through flexible hose (11) and impinges on the molten metal to force same into the pattern chambers. It is to be noted that there are separate sprues to each pattern, and that these sprues are of small cross-section; otherwise, the molten metal might run down the sprue hole prematurely.

Arc Furnace Type (Fig. 10 *B*). An ingenious arc furnace pressure casting machine used for casting supercharger buckets[4, 5, 23] is shown in Fig. 10 *B*. It is a totally enclosed arc furnace (1) with electrodes (2). In practice, the metal (3) is melted, the mold (4) is held securely by a clamp (8) on the furnace. The entire assembly is then inverted about trunnions (5) around the electrodes, the metal runs into the mold cavity (6) aided by air pressure admitted through (7).

Standard practice utilizes pressure from 5 to 25 psi. The permeability of investments is not great enough to permit casting by gravity, but is sufficient to permit casting with comparatively low additional pressure. Thin sections may be cast successfully in heated molds. Higher temperatures are generally more

effective than increased pressures. The high pressures used in metal die casting are not necessary since the molds are permeable and low heat conductors, the latter property permitting the metal to remain fluid longer. Standard investments will not withstand too high pressure, as their hot compressive strengths are about 400 psi., and the tensile strength about 100 psi.

(2) Centrifugal

Dental Type Machine. In Fig. 11, *A* is an illustration of a typical dental type centrifugal casting machine. In this type, the mold spins about an axis exterior to the mold.

This machine consists of an arm bar or beam (1) pivoted on a vertical axis shaft (2). It is motivated by a coiled spring (3) being held in a cocked position by a pin (4). This mechanism is contained in a base (5) secured to a table. At one end of the arm bar is a backstop (6) against which the mold (7) rests. A crucible or a melting furnace is placed at (8). To give a smooth rotation, a counterbalance (9) is placed at the other end of the arm and held in proper position by a

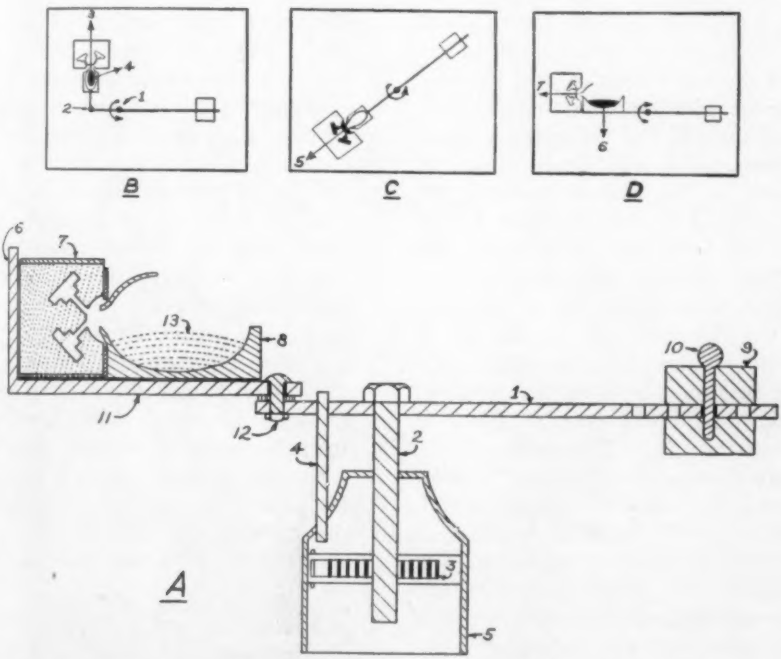


FIG. 11—A—TYPICAL DENTAL TYPE CENTRIFUGAL CASTING MACHINE. 1—ARM OR BEAM. 2—VERTICAL AXIS SHAFT. 3—MOTIVATING COILED SPRING. 4—COCKING PIN. 5—BASE. 6—BACKSTOP. 7—MOLD. 8—CRUCIBLE OR MELTING FURNACE. 9—COUNTERBALANCE. 10—COUNTERBALANCE PIN. 11—ARM SECTION. 12—PIVOT. B AND C—DRAWINGS ILLUSTRATING FORCES ACTING ON MOLTEN METAL IN PIVOTED TYPE CENTRIFUGAL CASTING MACHINE. 1—VERTICAL AXIS. 2—PIVOT POINT. 3—POINT OF PRINCIPAL FORCE OF INERTIA ON METAL AT INSTANT OF RELEASE. 4—ADDED FORCE OF INERTIA AFTER ARM HAS PIVOTED ABOUT (2). 5—DIRECTION OF CENTRIFUGAL FORCE AFTER MOLD ASSEMBLY HAS MADE A PORTION OF TURN. D—SOLID-ARM TYPE CENTRIFUGAL CASTING MACHINE SPINNING IN VERTICAL PLANE ABOUT HORIZONTAL AXIS. 6—DIRECTION OF INERTIA FORCE. 7—DIRECTION OF CENTRIFUGAL FORCE.

pin (10). The usual dental type has a straight arm bar. Another type[22] has a section of the arm bar (11) capable of rotating about a pivot (12), Fig. 11 *A*.

In operation, the arm bar is turned in a clockwise direction to wind the spring (3) to the required tension (2 to 6 turns). The pin (4) is raised to hold the bar in a cocked position. The metal (13) is molten, or molten metal is poured into the crucible (8). The counterweight (9) at the end of the bar is given a slight forward pull, the pin (4) drops and the entire assembly begins to spin about the central axis shaft (2). The centrifugal force generated caused the molten metal to run into the mold cavities, and the continuous spinning maintains this force until the effect of the spring is spent. Figure 11 *B* and *C* illustrate the forces on the molten metal in the centrifugal casting machine of the pivoted or "broken" arm type. The entire assembly spins in the horizontal plane about the vertical axis (1). The left end of the bar is "broken" and pivots about (2). At the instant of release, the principal force of inertia on the metal is shown as (3). The mold actually starts forward and then the "broken" arm is thrown to the left about (2), adding to the force of inertia (4). In the straight-arm type, the force should be almost entirely (4) and the metal tends to be thrown out of the side of the crucible. The "broken" arm tends to give a greater starting force parallel to the direction of the mold.

Figure 11 *C* shows the assembly after a portion of a turn, and the force is now centrifugal in the direction (5) and the metal is in the mold and held until it solidifies.

Figure 11 *D* illustrates a solid-arm centrifugal casting machine spinning in the vertical plane about a horizontal axis. The central arrow shows the direction of rotation. In this case, inertia tends to force the metal against the bottom of the crucible, as at (6), until rotation has built up centrifugal force (7) to force the molten metal into the mold.

New Type of Centrifugal Casting Machine for Multiple Molds. The dental type of centrifugal casting machine is excellent for a number of castings, but it permits the use of but one mold at a time. This can be overcome by using a battery of casting machines, or by a new type of design[4] that is being used in many variations. Figure 12 shows a machine of this general type. In it, the molds may be placed at both ends of the arm, or a number of molds may be placed around the circumference, each being fed from the center by gates, resembling the spokes of a wheel. For example, (1) is a base rotating about central shaft (2). It is motor driven with adequate speed control. Metal is poured from a ladle, or directly from a furnace (3) into a central pouring pit (4). The mold is rotating and the metal is forced into molds (6) and (7) through side gates or runners (5).

Factors Affecting Casting Time. An interesting study of centrifugal casting has been made by Myers[19] who shows the following: a dental casting using an 11-gauge sprue and five winds of the casting machine is made in 0.38 sec., at which time the machine has attained a speed of 528 rpm.

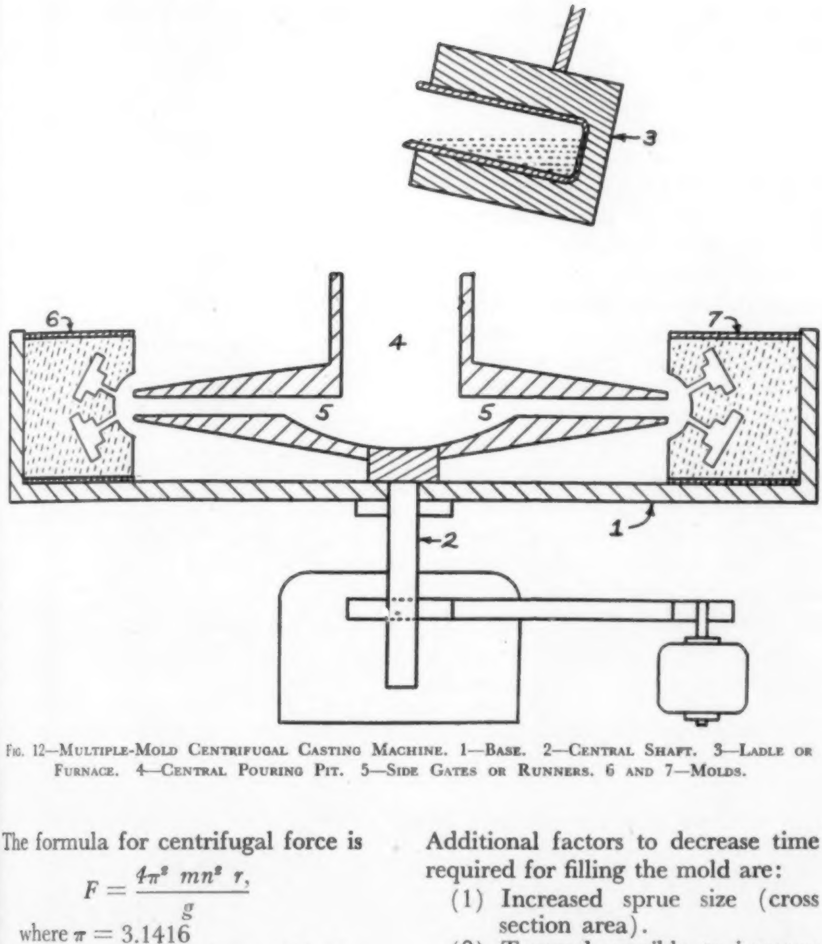


FIG. 12—MULTIPLE-MOLD CENTRIFUGAL CASTING MACHINE. 1—BASE. 2—CENTRAL SHAFT. 3—LADLE OR FURNACE. 4—CENTRAL POURING PIT. 5—SIDE GATES OR RUNNERS. 6 AND 7—MOLDS.

The formula for centrifugal force is

$$F = \frac{4\pi^2\ mn^2\ r,}{g}$$

where $\pi = 3.1416$
m = mass of the metal in lb.
r = radius of circular path in ft.
g = gravity constant (32.2).
n = number of revolutions per sec.

Thus the force is increased:

(1) Directly as the mass of metal *(m)*.
(2) Directly as the distance of metal from axis of rotation *(r)*.
(3) By the square of the speed *(n^2)*.

Additional factors to decrease time required for filling the mold are:

(1) Increased sprue size (cross section area).
(2) Tapered crucible to increase "head" of metal.

Many castings are completed in the first revolution of the machine. Pressures used (centrifugal or pressure) are from 5 to 25 psi.

After casting (pressure or centrifugal) into a hot mold cavity of 1.018 in. (Fig. 9 *B*), the metal will shrink 1.8 per cent and the resulting casting will measure 1.000 in. per original specification (Fig. 8 *A*).

RECOVERY AND COMPLETION OF CASTINGS

After the metal is cast, the mold

is permitted to cool at such a rate as will give the best physical properties to the alloy. A dentist quenches his mold from a red heat directly in water so as to maintain the gold in an annealed condition. Brasses usually need slower cooling and sometimes are permitted to cool down completely in the mold.

The investment is then "dug" away and the remainder brushed off with a stiff brush under running water. The next step is cutting off the sprues. This usually is done on an abrasive cut-off wheel or on a metal band saw. The remainder of the projecting sprue often can be removed on a disc sander.

Any final close tolerance machining now is done. This includes reaming, turning, tapping, and sometimes buffing.

Completed castings are inspected by standard machine shop practice; gages are used, including snap and thread gages, micrometers, dial gages, etc.

CASTING PRECISION

Figure 13 illustrates the precision possible in investment casting. The data were secured by measuring 100 patterns and castings at random from the production line. The average size of patterns and castings is used as the origin, plus or minus 0.000. Measurements were taken by means of a micrometer at 0.0005-in. intervals on patterns and 0.001-in. on castings, and the frequency or percentage which occurred at, above and below the average measurements were plotted as shown by circled points. The points were connected to give a frequency-tolerance curve. Broken lines indicate the tolerances for patterns and solid lines those for castings.

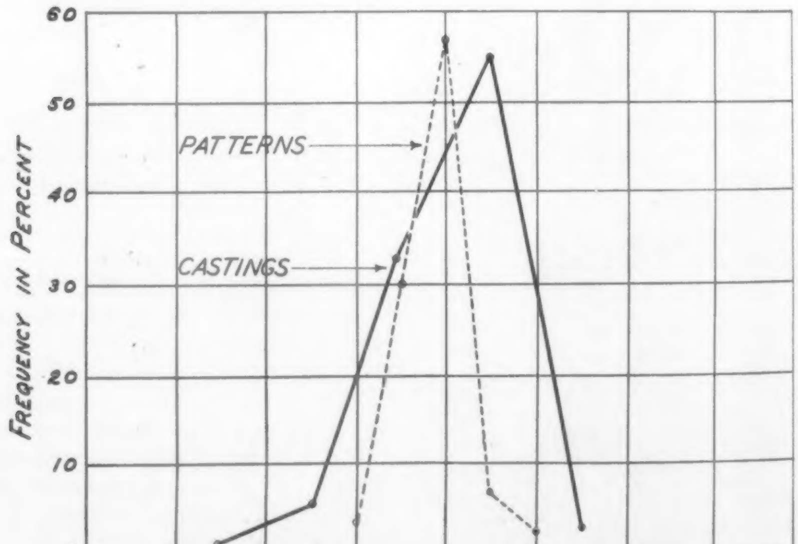


FIG. 13—TOLERANCE-FREQUENCY CURVES OF PATTERNS AND CASTINGS.

It is to be noted that 58 per cent of the patterns occurred at the average dimension and another 37 per cent (30 plus 7) were plus or minus 0.0005 in., or a total of 95 per cent were within a tolerance of plus or minus 0.0005 in., and 100 per cent were within plus or minus 0.001 in.

The curve of castings is of a similar shape, but covers a wider range of tolerance, as would be expected. Eighty-nine (89) per cent were plus or minus 0.0005 in. Another 9 per cent were plus or minus 0.0015 in., and the remaining 2 per cent were minus 0.0025 in.

The percentage of useful castings depends upon the tolerance permissible in the specifications. Obviously, those above size may be brought down to size, but undersize castings must be remelted and cast again. Where extreme accuracy is desirable, such as plus or minus 0.0005 in., it is possible to use 89 per cent of the castings. For this extreme precision, 89 per cent efficiency (11 per cent loss) is quite economical. This 11 per cent is not a total loss, as the metal can be remelted and cast again.

The foregoing figures were secured under carefully controlled conditions by the use of the latest developments in patternmaking and casting, and may be taken as the precision possible in in. per in. of length. These figures cover precision and are a scientific measure of the precision casting process. This shows the variation of one pattern or casting from another or from the average dimension.

The practical measure is known as accuracy and involves the measure of tolerance from the specified dimensions. For example, the casting used as an illustration herein had a specified dimension of 1.000 in., plus or minus 0.003 in. If the average dimension of our casting is 1.000 in., then all would pass the requirements and the accuracy would be met 100 per cent. If the average casting dimension is 1.004 in., then most of the castings would be rejected and the accuracy would be low even though the precision is high.

High precision shows that the material and process is working very uniformly. Low accuracy may be due to the use of incorrect values in the compensation calculations. The use of 2.4 per cent instead of 2.0 per cent for the shrinkage of brass will cause the casting to be 0.004 in. too large. If the die was to be 1.015 in. but was made 1.019 in., the same large casting would result. Considering the possible combined errors in our available figures for the shrinkage of wax patterns, the setting and thermal expansion of investment and the casting shrinkage of the alloy, it is advisable to double the above illustrated precision tolerance to secure a commercially feasible accuracy tolerance.

A wide variation in precision is difficult to correct, but errors in accuracy can be more easily eliminated. For example, if the castings are uniformly 0.004 in. oversize, it is only necessary to make the die 0.004 in. smaller. The possibility of making dies quickly and cheaply is a great aid in making precision castings accurate. Once the die is made to the correct determined size, the accuracy of the casting can be made nearly the same as the precision.

CONCLUSIONS

Having reviewed the theory and practice of precision casting, it is now in place to compare its applications with those of other methods.

(1) Fields of Application of Precision Casting

The fields of application for the precision casting method may be summarized as follows:

(a) The principal indicated field of precision cast parts is to displace those requiring many machining operations or hand fabrication.

(b) Where alloys are unusually difficult to machine.

(c) Many parts have specifications calling for tolerances of plus or minus 0.005 in. (decimal dimensions) and 1/64 in. on fractional dimensions, with one or several dimensions held to very close limits, such as plus 0.0007, minus 0.0003. Here a part can be precision cast to all but the latter extreme tolerance, and this would be so nearly to size as to require only a finishing cut in machining.

(d) Where a smooth, clean surface adds utility and beauty.

(e) For small runs where other pattern or die costs are too expensive or time consuming to produce.

(f) Where special metallurgical and metallographic conditions are required.

(g) To produce sizes and shapes wherein suitable bar stock, tubing or forgings are not available.

(h) As a starting point for machining wherein a sand casting is too rough or inaccurate to permit proper chucking. Here the investment process can be used and economies secured by easing up on tolerance requirements.

(i) To provide special markings, numbers, graduations, blind holes, etc.

(j) Where the presence of a parting line is unsightly or too inaccurate, and where appreciable draft is undesirable.

(2) Cost of Precision Casting

In this most important factor, it must be stated that a precision casting is more costly to produce than a sand casting. However, in all fairness the cost of a precision casting must be compared with a sand casting on which there has been carried out those machining operations necessary to meet specifications. Likewise, when a precision casting requires some critical machining, this cost must be added before a fair comparison can be made with a totally machined part. In comparing costs with die casting, it is necessary to take into account original die cost and the life span of the die.

Whereas sand castings usually are sold on a per lb. basis, precision castings usually are sold as finished pieces. It is comparable to a machined part where finishing cost usually far exceeds the cost of the metal, and a small part may be much more costly than a less intricate large part.

With more experience in the comparatively new precision casting field and with utilization of mechanized mass production methods, costs will be lowered and more precise figures will become available for direct comparison with those by other methods. At present, each job involves something new, and costs are merely estimates.

(2) Future Work

Some of the paramount desires of the precision caster, and ones on which the various research departments are working, are:

(a) Materials

(1) Harder low-fusing die metals.
(2) Waxes with less shrinkage.
(3) More refractory and less costly investments.

(b) Equipment

(1) Automatic patternmaking machines.
(2) Larger casting equipment.

As improvements in materials and enlargement of equipment are made, it will be possible for investment to replace permanent molds, sand and sand cores in more and more types of casting work.

Precision casting is not a process that just any foundry can adopt at present. It requires equipment, apparatus and materials that present users have developed and built for their own use, and materials especially formulated for their process. It is believed that, as these means are perfected to a point where consistent results will be possible without constant scientific supervision, the process can be made more generally available. Just as Dr. Taggart[3] developed dental casting and then made his materials and apparatus available to others, so precision casters will do likewise. At present, no two investments or casting machines are alike; once the merits of each are more widely known and generally available, one may look to rapid improvement and growth of precision casting practice.

Industrial Practice

Figures 14 to 20 illustrate operations in a precision casting foundry.

Figure 14 shows a mold being invested. Note the graduate for measuring water, scale for weighing investment to ¼ oz. accuracy, and clock for accurate timing of the mixing operation. The mold is vibrated electrically to permit the investment to level itself quickly. Investment is spatulated by the electrically-driven blade mixer.

Figure 15 shows a battery of 24 electric furnaces for dissipating or burning out the patterns. They are provided with individual and averaging thermocouples for temperature measurements and automatic and electronic controls for regulating temperature, heating rate, cut-off time and air flow to sweep out vapors and combustion products.

Figure 16 shows a high-frequency induction furnace for melting metal and a large casting machine based on the principles of the dental pressure casting machine of Fig. 10. Note the thermocouple and pyrometer for accurate metal temperature measurement, time clock and gages for accurate controls.

Figure 17 shows a group of dental type centrifugal machines adapted to take large molds and special crucibles. A helper loads and unloads the molds and the melter follows in succession from one machine to another. Note the control dials for the burn-out furnaces (to the right of the melter).

Figure 18 shows the molds being broken up and the castings being "dug out." Note the castings in the front and rear and some still under water.

Figure 19 shows a band saw for cutting the castings away from the sprue and a sander for removing the sprue stumps from the casting to give a surface flush with the casting.

Figure 20 shows the gaging of castings for dimension as well as the inspection of patterns and castings for imperfections.

LABORATORY CONTROL

The section dealing with the principles of precision casting has illustrated the interdependence of the

FIG. 14—MIXING INVESTMENT AND INVESTING MOLD.

FIG. 15 — BATTERY OF ELECTRIC BURN-OUT FURNACES.

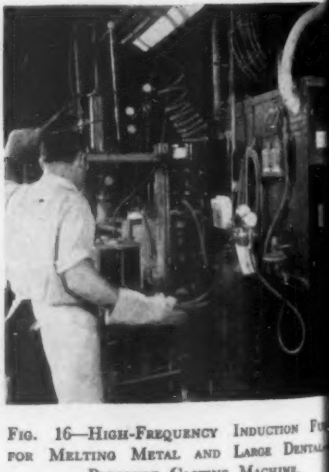


FIG. 16—HIGH-FREQUENCY INDUCTION FU[RNACE] FOR MELTING METAL AND LARGE DENTAL PRESSURE CASTING MACHINE.

FIG. 17—GROUP OF DENTAL TYPE CENTRIFUGAL CASTING MACHINES.

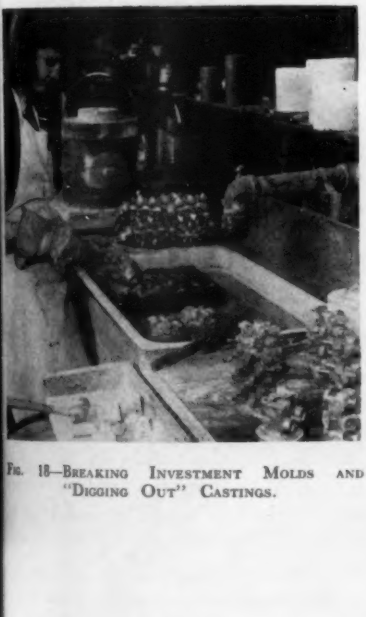


FIG. 18—BREAKING INVESTMENT MOLDS AND "DIGGING OUT" CASTINGS.

FIG. 19—BAND SAW FOR SPRUE CUT-OFF AND SANDER FOR REMOVING SPRUE STUMP.

FIG. 20—GAGING AND INSPECTION OF PATTERNS AND CASTINGS.

physical units of length, mass, temperature and time. The successful production of precision castings depends upon proper control of these factors.

(1) Precision entails — means for assuring reproduction of contions (mass, temperature and time).

(2) Accuracy entails—knowledge of dimensional (length) changes of all materials used.

The illustrations (Figs. 14 to 20) show the ever presence of instruments and apparatus to measure and automatically control the conditions necessary for precision.

The maintenance of accuracy has its foundation in the research and control laboratory, where the physical properties of all materials are determined and standards maintained. The most important properties include setting and thermal expansion measurements (dilatation).

Figure 21 shows a precision micrometer comparator. In the illustration, a V-shaped trough is filled with a mixture of investment in the plastic state and metal markers are set therein about 10 in. apart. The micrometer microscopes are focused thereon, and the expansion on setting is followed and measured in units of 0.000005 in. per in. of specimen length.

This comparator also is used to measure expansions near room temperature of materials, such as waxes. A controlled constant temperature water bath is used instead of the trough. The curves in Figs. 2 and 3 were determined on this instrument.

Figure 22 shows Bureau of Standards type dilatometers for measuring thermal expansion by the fused quartz method. At the left is a dilatometer with fused quartz tube assembly. The expansion (and contraction) of the specimen during heating is indicated on the dial gage in terms of 0.00001 in. per in. of specimen length. In the center of the illustration is a potentiometer pyrometer for measuring temperature by means of thermocouple wires attached to the center of the specimen. At the right is another dilatometer, also an exact replica of that used at the Bureau of Standards. The data for Figs. 3 to 7 were determined on these dilatometers.

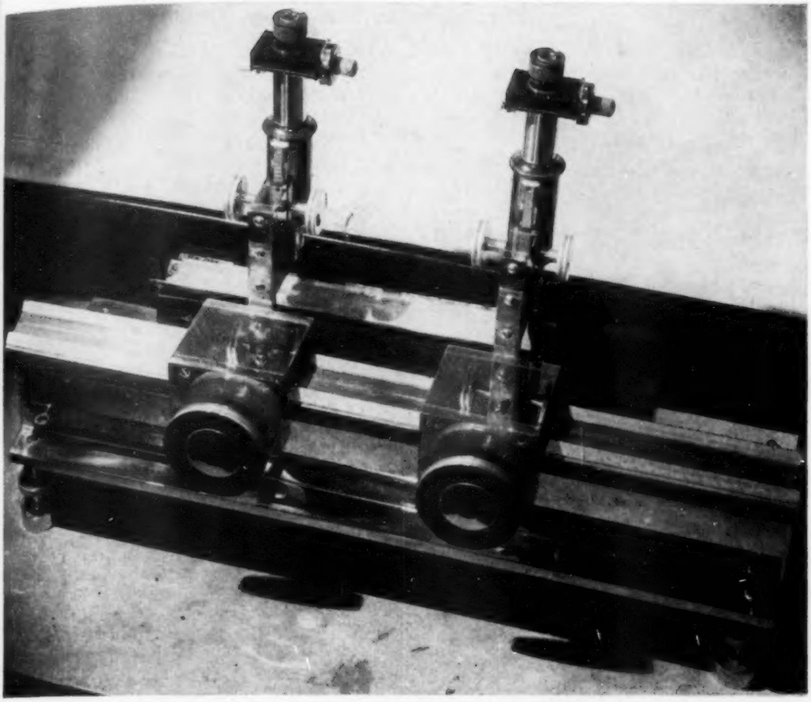


FIG. 21—PRECISION MICROMETER COMPARATOR. THE "V" TROUGH IS FILLED WITH PLASTIC INVESTMENT MIXTURES.

FIG. 22—DILATOMETERS (BUREAU OF STANDARDS TYPE) FOR MEASURING THERMAL EXPANSION BY FUSED QUARTZ METHOD. LEFT—DILATOMETER WITH FUSED QUARTZ TUBE ASSEMBLY. CENTER—POTENTIOMETER PYROMETER FOR TEMPERATURE MEASUREMENT. THERMOCUPLE WIRES ARE ATTACHED TO CENTER OF SPECIMEN.

ACKNOWLEDGMENT

Acknowledgment is made to the author's associates of the Whip-Mix Corporation; C. E. Armbrecht, technical director, in the design of equipment and development of process; to Miss Betty Luster, the author's assistant, in the preparation of the manuscript and illustrations, and to E. A. Steinbock, president, for making it possible to publish this paper.

(See following pages for Appendix, Bibliography and Discussion)

Appendix I

PATTERN WAX FORMULAE

No. 1	Per Cent
Paraffin (55° C.)	60.0
Carnauba	25.0
Ceresin	10.0
Beeswax	5.0

No. 2	Per Cent
Paraffin	4.0
Stearic Acid	43.0
Damar	43.0
Beeswax	6.0
Tamarack	4.0

No. 3	
Paraffin (120° F.)	30.0
Carnauba	30.0
Ceresin	20.0
Beeswax	10.0
Damar	10.0

No. 4	
Paraffin (70° C.)	35.0
Carnauba	10.0
Beeswax	55.0

No. 5	
Diglycol Stearate "S"	16.5
Acrawax "B"	19.5
Beeswax	22.0
Ceresin	42.0

No. 6	
Paraffin	10.0
Carnauba	40.0
Beeswax	10.0
Rosin	40.0

No. 7	
Ozokerite	61.0
Paraffin	29.0
Rosin	10.0

No. 8	
Ceresin	70.0
Beeswax	30.0

No. 9	
Beeswax	67.0
Rosin	33.0
Venice turpentine (small amt.)	

No. 10	
Beeswax	1 lb.
Venice turpentine	1 oz.
Glycerine (few drops)	

NOTES: The above formulae were found in references[8] and[20], also in catalogs and from private sources.
Formulae 1 to 4 are recommended for dentists[8].
Formulae 5 to 10 are recommended for jewelers and precision casters.

Appendix II

INVESTMENT FORMULAE

No. 1[8]	Per Cent
Plaster of Paris	30.0
Silex (powdered)	70.0

No. 2[8]	Per Cent
Plaster of Paris	52.0
Marble dust	16.0
Graphite	16.0
Soapstone (powdered)	16.0

No. 3[8]	
Plaster of Paris	50.0
Powdered mica	25.0
Marble dust	25.0

No. 4[9]	
Alpha gypsum (21)	30.0
Silica (200-400 mesh)	62.0
Andalusite (fine)	5.0
Alundum (fine)	1.0
Boric acid	2.0

No. 5[10]	
Plaster of Paris	30.0
Cristobalite	50.0
Tridymite (and silica)	20.0

No. 6[11]	
Calcined gypsum	30.0
Silica	69.0
Strontium chloride	1.0

No. 7[13]	
Calcined gypsum	80.0
Asbestos fiber	20.0

No. 8[14]	
Plaster of Paris	60.0
Silica	25.0
Talc	15.0

No. 9[16]	
Silica	67.0
Liquid: tetraethyl silicate 8 vol.; water 1 vol.; alcohol 1-2 vol.; hydrochloric acid (few drops)	33.0

No. 10[17]	
Silica	90.0
Magnesia	6.0
Monobasic ammonium phosphate	3.0
Monobasic sodium phosphate	1.0
Liquid—water or 10 per cent hydrochloric or nitric acid	

NOTES: Numbers of above formulae refer to type.

Formulae 1 to 3 are old types of dental investments of low expansion. Formulae 4 to 6 are new types dental investment of high expansion. Formulae 7 and 8 are mixtures for plaster casting. Formulae 9 and 10 are investments for stainless high fusing alloys.

Bibliography

1. Philbrook, B. F., *"Cast Fillings,"* TRANSACTIONS, Iowa State Dental Society, pp. 277-278, (1896-97).

2. Taggart, W. H., *"A New and Accurate Method of Making Gold Inlays,"* DENTAL COSMOS, vol. 49, pp. 1117-1121, (Nov., 1907).

3. Wolf, J. D., *"Precision Castings for Ordnance and Aircraft,"* METALS AND ALLOYS, pp. 784-788, (Oct., 1943).

4. Wyman, L. L., and Basch, D., *"Precision Castings,"* THE FOUNDRY, pp. 116-118, 204-206, (Feb., 1944).

5. Merrick, A. W., *"Precision Castings of Turbosupercharger Buckets,"* THE IRON AGE, pp. 52-58, (Feb. 10, 1944).

6. Coleman, R. L., *"Physical Properties of Dental Materials,"* Bureau of Standards Journal of Research, vol. 1, no. 6, pp. 867-938, (Dec., 1928) (R.P. 32).

7. Taylor, N. O., Paffenbarger, Geo. C., and Sweeney, W. T., *"A Specification for Inlay Casting Wax,"* JOURNAL, American Dental Association, pp. 40-52 (Jan., 1931).

8. Prinz, Hermann, DENTAL FORMULARY, Lea and Febiger, Phila., 5th Edition, (1936).

9. Dailey, M. C., U. S. Patent No. 1,901,052, March 14, 1933.

10. Coleman, R. L., and Weinstein, L. J., U. S. Patent No. 1,932,202, Oct. 24, 1933.

11. Neiman, Robert, U. S. Patent No. 2,247,395, July 1, 1941.

12. Souder, W. H., and Hidnert, Peter, *"Thermal Expansion of Nickel, Monel Metal, Stellite, Stainless Steel and Aluminum,"* Scientific Papers of the Bureau of Standards, no 426, p. 517, Dec. 17, 1921.

13. Hagemeyer, H. F., U. S. Patent No. 2,201,037, May 14, 1940.

14. Bean, Morris, U. S. Patent No. 2,220,703, Nov. 5, 1940.

15. Taylor, N. O., Paffenbarger, Geo. C., and Sweeney, W. R., *"Dental Inlay Casting Investments Physical Properties and a Specification,"* JOURNAL, American Dental Association, 17, pp. 2266-86, (Dec., 1930).

16. Prange, Charles H., U. S. Patent No. 1,909,008, May 16, 1933.

17. Prosen, E. M., U. S. Patent No. 2,209,035, July 23, 1940.

18. Burgard, L. C., U. S. Patent No. 1,757,991, May 13, 1930.

19. Myers, Raymond E., *"Time Required to Cast Gold by Centrifugal Force,"* JOURNAL, American Dental Association, vol. 28, pp. 2001-2017, (Dec., 1941).

20. THE FOUNDRY, pp. 184, April, 1944.

21. Randel, W. S., and Dailey, M. C., U. S. Patent No. 1,901,051, Mar. 14, 1933.

22. Gardner, J. A., and Gardner, D. S., U. S. Patent No. 17,783 (Reissue), August 26, 1930.

23. Patented or Patent Pending, numbers, etc., not available.

DISCUSSION

Presiding: A. K. HIGGINS, Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Co-Chairman: NATHAN JANCO, Centrifugal Casting Machine Co., Tulsa, Okla.

MEMBER: What is the production rate for one machine on typical industrial or ordnance parts?

MR. NEIMAN: The production rate for one machine and about 10 unskilled operators, if the casting does not weigh over 2 oz., is one casting per min., or 1500 castings per 24-hr. day.

MEMBER: How large a casting is it practical to make with the investment molding process?

MR. NEIMAN: So far, castings have been made weighing up to 5 lb. Due to burnout furnace size limitations, we have confined ourselves to molds of not over 5-in. maximum

diameter, or length. In the same furnace space we could get one 5-lb. casting or about 45 one-oz. castings. Our demand has been for small, intricate shapes rather than size.

CO-CHAIRMAN JANCO: I might mention that some castings are being made that weigh over 100 lb.

MEMBER: Do you use tridymite or cristobalite?

MR. NEIMAN: Cristobalite is used by some concerns. We do not use either.

MEMBER: As far as I know, this paper presents, for the first time, various technical data in sufficient detail to put precision casting on an engineering basis. A recent instance in precision casting is the die casting of ordinary zipper fasteners. The die in which the zippers are cast is made by powder metallurgy. The mold, into which the iron powder is pressed to make the die, is precision cast.

J. W. JUPPENLATZ[1]: What are the size limitations, at the present time, on investment steel casting? Also, is it feasible, in the larger steel castings, especially those of thick section, to use static casting in a manner which is comparable to the regular foundry molding and casting practice?

MR. NEIMAN: As to the adaptability of investment for steel castings, at present steel castings usually are of small size and investments are somewhat costly. Investments usually have high expansions and low heat conductivity, so that, in heating, one part of the mold usually will be hotter than another, and mold cracking will result.

Investments are of low permeability and are not well adapted to static casting. In fact, the success of investment casting is due to the fact that pressure (direct or centrifugal) is used. Also, investment molds are used hot or vented to increase metal flow.

Investment molds are used for casting by vacuum, pressure, or centrifugal (about its own or an exterior axis) means. Combinations of these are possible.

I believe that it is safe to say that investments can be made to suit any reasonable need. Such problems usually entail persistent work and close cooperation between the investment maker and the foundry.

MEMBER: How is the slag prevented from going into the mold?

MR. NEIMAN: Usually, the slag is lighter and, in a centrifugal casting, remains behind; in pressure casting it remains on top of the metal.

MEMBER: The investment material can be used but once?

MR. NEIMAN: The investment material can be used but once; so far this is true. However, with expensive investment materials, no doubt, some reclamation method can be developed. Of course, by using the investment but once we do not have to worry about change in cavity dimension due to build up of dies, as is true with permanent molds. Investments are comparatively inexpensive, or will be when the demand becomes larger.

To go a step further: one of the good features of investments is the fact that they form a one-piece mold encasing many intricate patterns (a stack mold in one piece); as such, the mold must be broken apart to recover the castings. If investments be used in split molds (cope and drag) wherein the casting can be removed, it has been possible to use some investments several times.

MEMBER: One organization is using a silica flour for the immediate refractory next to the part to be cast. Is that straight silica flour or does it contain ingredients?

MR. NEIMAN: Silica flour in itself would have no strength and it must have some

[1] Lebanon Steel Foundry, Lebanon, Pa.

binder. That is, even in foundry work we have to use clay or some other material to hold the silica together.

MEMBER: It is in the form of a paste. Would that be just a straight water mixture or would this paste have a chemical binder?

MR. NEIMAN: It would have a chemical binder of some nature. I might state that the strength of the investment usually is about 400 psi. at 1200° F. That varies quite a bit. Some investments are strong and some weak, depending upon the nature and amount of binder.

MEMBER: Can normal sources of water be used in this process?

MR. NEIMAN: Investments are now on such a basis that the effects of normal impurities in water are negligible.

MEMBER: Have you had any experience excepting in brass?

MR. NEIMAN: We have done most of our work on producing parts that had original specifications for machined yellow brass of 50,000 psi. tensile strength and 30 per cent elongation. To meet this, alloys had to be chosen that would give 50,000 psi. and about 30 per cent elongation in the "as cast" state. Investment castings produce about the same strength as sand castings, although the metal will cool a little more slowly in investment, but if necessary the investment can be broken away a little more quickly. Manganese bronzes work very well. Aluminum bronzes have worked well. High-copper alloys do not cast well in plaster, nor do high-lead alloys, but there are special investments being made to take care of that. Platinum is cast in dentistry. It has a melting point of 3500° F. In the case of brass, we usually use the ingot to start with. The furnace charge is about 17 lb. and pouring is continuous.

We have had very little experience with steel casting, commercially. Research work shows that steel has a tremendous affinity for refractories (investments) and much work will have to be done to secure the smooth surface we desire. Work to date indicates that such smooth-cast surfaces can be secured and that the investment can be removed without sand blasting, which dulls sharp edges.

Design and Safe Operation of Centrifugal Casting Machines

By James G. Weber*, Milwaukee, Wisc.

Abstract

While the practice of centrifugal casting was first instigated at the beginning of the nineteenth century, it did not come into popular usage until the early 1920's when the process was begun to be widely used for the production of symmetrical parts such as gears and cylinder liners. However, only a few people have carried the practice into a wide and variable field, chiefly because of the inherent problems and dangers connected with the process, as well as the wide divergence from the field of static casting. Since 1930 there has been a diligent investigation by some foundries into the application of centrifugal force as a pressure medium for producing sound castings, both in the centrifugal field as well as in centrifuging. These investigations, however, were and are usually carried on with a mind toward quality, quantity, and low cost, with a pitiful disregard of the tremendous destructive forces which are hidden within the spinning equipment. Too often has management learned of these forces at the cost of human life or the burden of a hopeless cripple. It is the purpose of this paper to bring to light some of these hidden forces.

Centrifugal Casting Equipment Design

1. The company with which the author is connected began its work in centrifugal casting in 1927. While methods at that time were extremely crude, the need for safe operation was soon recognized. Centrifugal equipment was not designed on a basis of engineering principles, chiefly because there were few precedents in the field, lack of personnel, and the amount of literature available negligible. But withal, the machines were guarded as well as possible to the extent deemed necessary, and sometimes beyond safety requirements. This policy has proved itself by the few injuries resulting from centrifugal casting, there being no fatal accidents and only one permanent injury.

2. *Safety Standards:* With the advancement of research into the values of centrifugal casting, the machinery requirements were analyzed and incorporated into the equipment, safety always being the chief factor of design. We feel, therefore, that the units used at present are the most adaptable for our needs, as well as giving full protection to the operators. The machines are checked frequently, even when running smoothly, and the men in charge have somewhat of a sixth sense which forewarns them when danger is approaching.

---

* Ampco Metal, Inc.

Note: This paper was presented at a Centrifugal Casting Symposium Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 27, 1944.

3. To maintain such standards, the author's company designs and supervises the construction of all its own centrifugal casting machines. The design is not planned from a standpoint of how the machines should operate, but how they will operate when turned over to production.

4. *Centrifugal Force:* First of all, there is the potential energy of centrifugal force, mathematically expressed as mw^2r, or

$$m\frac{v^2}{r},$$

'w' being the angular velocity in radians per second; 'v' the tangential velocity in ft. per sec. at the radius considered; 'm' the mass of the body, which is the weight in lb. divided by the gravitational acceleration; and 'r' is the radius from the center of rotation to the center of the mass, measured in ft.

5. Whenever a mass rotates the centrifugal force is always present and increases directly as the square of the rpm. and directly as the length of the radius.

6. Putting the meaning of these mathematical terms into more familiar situations, we can better understand the monster with which we are dealing. Suppose the cover of a mold is held down with a number of ¾-in. bolts spaced equally on a 20-in. bolt circle, and assume that the mold is rotating at 1500 rpm. Each of these bolts would weigh the equivalent of 639 lb. This represents a terrific strain on the cover and mold. Likewise, if the die were of 20-in. diameter the bursting strain on the mold drum would be 5600 psi. while the metal was molten, which is the critical period in the casting cycle. Beware then of thin-walled mold drums, or the metal will burst through with volcanic force and destruction.

7. *Velocity:* Another force seldom considered is the velocity developed in the parts of a rotating mass. Returning to our cover bolts, if one of these were to break loose the destructive force would be the equivalent of dropping a building brick on a man's head from a height of 16 ft.

8. Centrifugal dies should be centered and dynamically balanced as much as possible. This is true not only from a casting angle to obtain concentric bores, but also from a standpoint of safety. Assume that a 100-lb. casting 20 in. long is poured into a die which is ⅛-in. off center. The unbalanced force at 1500 rpm. would cause a bending moment of approximately 25,000 in. lb., which is approaching the safe limits of a 3½-in. shaft without even considering dead load and shock load. Also, an additional 1600-lb. load is placed on the bearing. These conditions, of course, will vary considerably with the individual type of construction, but they give an average cross section as to what may be expected.

9. Essentially, a centrifugal casting machine should incorporate all the safety factors possible, based on a thorough knowledge of dynamics and statics. In the main, shafts need be designed only for bending, as the torque usually is insignificant in comparison to the bending moment. As an example, an

instance may be cited where the spindle shaft measures 4 in. in diameter, while the motor shaft is of only ¾-in. diameter. For the same reason, it will seem odd to see two "B" section V-belts driving a 3¾-in. shaft.

10. *Bearings:* Because of the difficulty in aligning dies and molds concentric with the center of rotation, ball or roller bearings are superior to sleeve bearings. The lubrication problem is also simpler, as sealed bearings, a practical necessity in a foundry, can be used. Sleeve bearings allow too much vibration in this type of work.

11. *Vibration:* Critical vibration speeds should be kept quite low, to avoid the possibility of operating at or near a critical point.

12. Some work has been done on self-centering molds, which type allows the entire unit to rotate about the center of gravity. Such applications have been successful in the case of wash driers, flour sifters, sand sifters, and sugar centrifuges. But, in handling a material such as liquid metal, it is the author's opinion that a firm foundation is far superior, as this type of construction tends to dampen vibration and prevent eccentricity from developing further. It would also be difficult to make a thin-walled casting on a freely-mounted spindle. Dry packing of foundations rather than pouring is also a superior method of obtaining rigid footings.

13. *Heat Warpage:* Warpage of the various parts of a centrifugal casting machine is probably the largest source of danger. This effect, due to the heat involved, can distort a shaft during operation in such a manner that the entire load is shifted. Considering our calculations of centrifugal force, we can readily see that the bending moment is immediately increased, and this produces still more deflection. The action, therefore, is cumulative and rapid, usually ending in a broken shaft or a shattered bearing. To prevent this danger shafts can be cooled by various means, such as air fins or water circulation. Warpage also causes danger in that metal creeps under covers and between partings, spraying the surrounding area.

14. Whenever possible, centrifugal dies should be self-centering. This can be accomplished by various methods, such as rotating rings, tapers, etc. The advantage obviously lies in the fact that the casting will be symmetrical and the mechanical stresses less.

15. *Centrifuging:* Centrifuging presents problems similar to centrifugal casting, but different in detail. It is sometimes possible to locate the casting so that part is centrifuged and other parts a true centrifugal. In other cases, the entire casting lies on one side of the center of rotation. This is truly a centrifuged casting, and depends upon centrifugal force to merely cast under pressure, similar in effect to die casting. For centrifuging, much less angular velocity is required, which is a distinct advantage. In some cases, the die is counterbalanced to offset part of the unbalanced weight. More often, a number of castings are placed symmetrically about a common sprue. This

not only balances the setup, but also increases production, provided, of course, the intricacies of molding do not slow down the operation.

TYPES OF CENTRIFUGAL CASTING UNITS

16. Figure 1 represents the general type of casting machine used for light work. It shows the bearing housing completely sealed, which eliminates all grit and dust. This type of unit can be swiveled at *A, B,* or *C* to provide a variable pitch to the axis of rotation. The drive can be electric, hydraulic or pneumatic, belted or direct coupled. For production setups constant speed is sufficient, but for jobbing variable speed is necessary. A circulating oil lubrication system will help materially in cooling the bearings and the shaft. Also, the proper design of face-plate will set up a cooling stream of air.

17. In an instance where one of these units was operating in a vertical position, a screwed cover broke loose and sailed like a phonograph record across the room. Luckily, there were no heads in the way, and the 10-lb. cover spent itself by bouncing on the floor and rolling into a pit. The metal had already frozen, so there was no splash. But in one other instance, when operating horizontally, a ring of metal 10 in. in diameter which had formed on the cover tore loose and aimed itself at the operator's face. He turned his back but was hit on the hand, badly ripping the flesh. In another case, the die holder split in half radially, but a serious accident was averted because the metal had frozen and acted as a pin. There have also been cases where the mold exploded due to moisture, an inexperienced man poured metal into a mold that was already filled, and so on. But these incidents usually result in no damage, due to the guards which encase the spindle.

18. Figure 2 shows another variation of a spindle mounting. These bearings are grease lubricated and sealed against dust. Units of this type are used

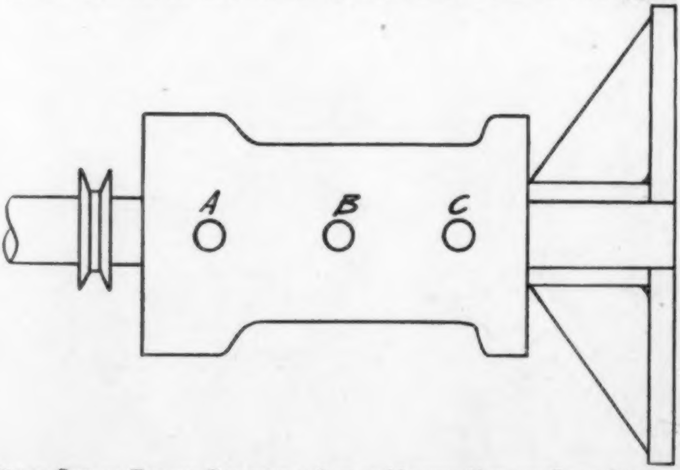


FIG. 1—VIEW OF GENERAL TYPE OF CENTRIFUGAL CASTING MACHINE USED FOR LIGHT WORK. UNIT CAN BE SWIVELED AT POINTS A, B OR C TO PROVIDE VARIABLE PITCH.

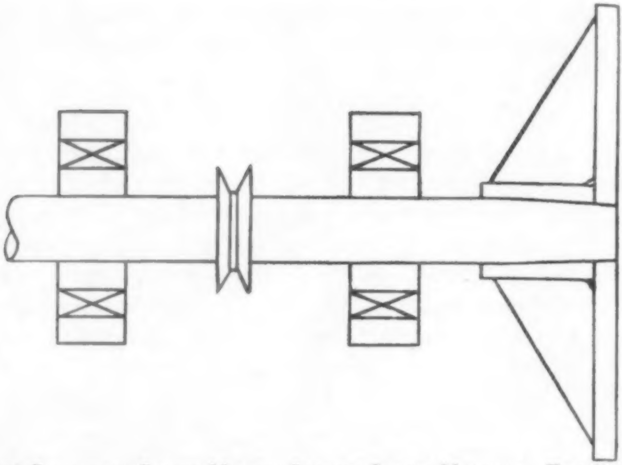


FIG. 2—VIEW OF CENTRIFUGAL CASTING MACHING SHOWING SPINDLE MOUNTING. THIS TYPE OF UNIT IS USED FOR CASTINGS WEIGHING UP TO 1200 LB.

for castings weighing up to 1200 lb. Serious consideration must be given the bearing just back of the face-plate. This bearing is carrying double the load of the tail bearing. Care must also be taken that the tail bearing does not lift off the foundation, or lift the foundation with it. The force on this bearing is up, and not down.

19. The unit represented in Fig. 3 is designed for pouring a casting from each end. It is a foreign design and, theoretically, highly efficient. But in practice, dangerous vibrations travel back and forth along the shaft. Vibration generally is bad. In the east, one of these units was being used. During the pouring of a casting, one of the face-plates vibrated off, threw the oper-

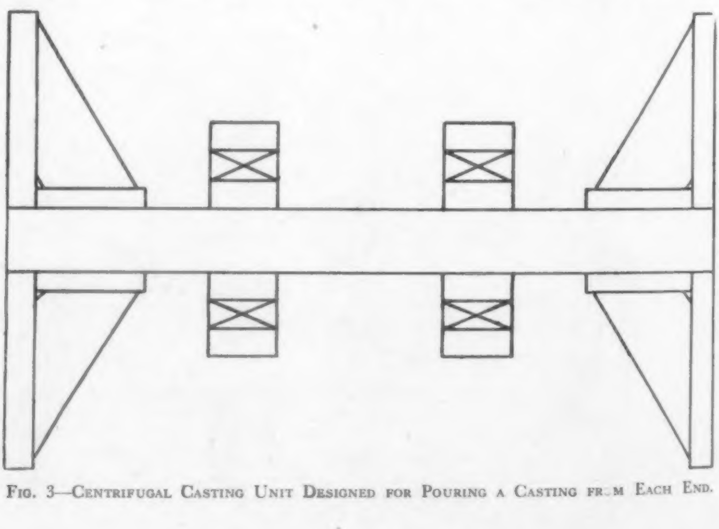


FIG. 3—CENTRIFUGAL CASTING UNIT DESIGNED FOR POURING A CASTING FROM EACH END.

ator on the floor, and poured the half-finished casting around him. He managed to flounder out, but died shortly afterward of burns.

20. Figure 4 shows a type of unit which is called a cradle machine. Most foundrymen have seen this type of unit. It is comparatively the safest construction, even when used without the upper set of rollers, which is sometimes done when the casting is long in comparison to the diameter, and the speeds are conservative.

21. These units are more or less limited to horizontal work, as thrust offers a serious problem when mounted at an angle over 7° from horizontal. However, this general construction can be used in vertical work, also.

22. Figure 5 shows a very common method of attaching a face-plate to a shaft. These face-plates frequently become loose due to heat. They usually are held in place with setscrews, one being located over the key.

23. An improvement that might be suggested is putting webs on the face-plate. This will materially strengthen the plate and also act as a fan for cooling. Another suggestion is to drill the shaft and use a dog-point setscrew. This will at least keep the face-plate from sliding off, even if it does become loose.

24. A taper fit, such as shown in Fig. 6, has been found much more satisfactory. The face-plate is heated lightly, and then pulled tight by means of an end plate and tap bolts, the end of the shaft being drilled and tapped. The tap bolts are locked with a wire ring sewed through holes in the bolt head, or lock washers can be used. With this construction, as the face-plate heats up it expands back along the taper, automatically tightening itself on the shaft. The author has never had one of these plates become loose due to heat.

25. When using such fits, it must be kept in mind that the included angle must be 7° or less to obtain a self-locking taper. It is also necessary to have at least 1/16-in. clearance between the key and the keyway in the hub. Otherwise, there is danger that the hub will ride the key instead of the shaft, if not carefully fitted. It usually is advisable to lock the key to the shaft by means of countersunk or flathead screws.

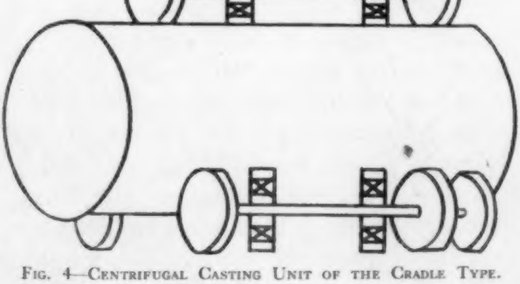


FIG. 4—CENTRIFUGAL CASTING UNIT OF THE CRADLE TYPE.

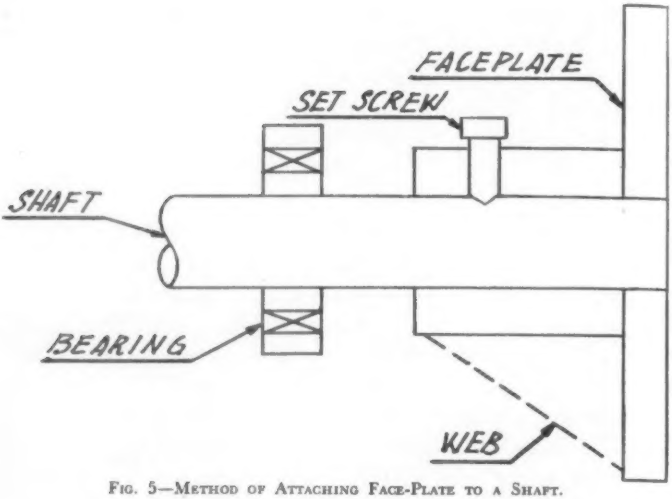


FIG. 5—METHOD OF ATTACHING FACE-PLATE TO A SHAFT.

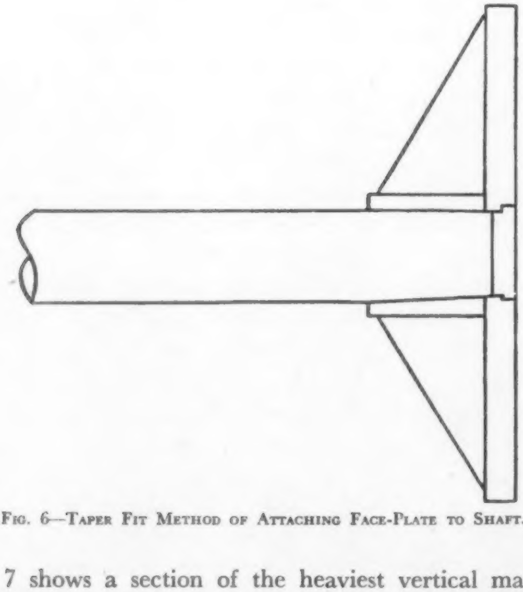


FIG. 6—TAPER FIT METHOD OF ATTACHING FACE-PLATE TO SHAFT.

26. Figure 7 shows a section of the heaviest vertical machines used by the author's company. This section was selected to show an analysis of forces. First, let us look at the illustration at the lower left-hand corner. We all know the great lifting and dividing force of a wedge. A light blow of a hammer, or a force 'W', will exert a lifting or splitting force 'F', depending on the angle θ. Now if we look at the face-plate, we see that the weight placed on the face-plate exerts a large breaking stress on the hub. Here again, we must carefully balance the taper against the strength of the hub,

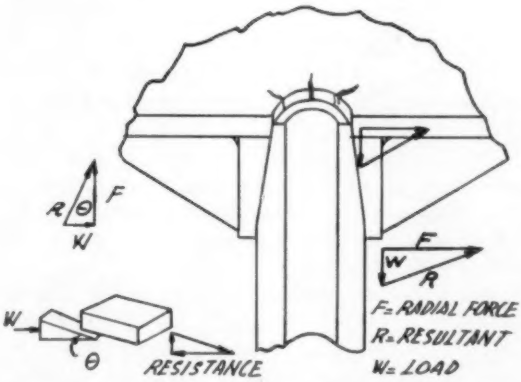


FIG. 7—SECTIONAL VIEW OF HEAVY VERTICAL CENTRIFUGAL CASTING MACHINE.

or serious rupture will occur, resulting in an accident. Such considerations usually are taken lightly, but they can be serious. It is advisable to have the engineers design the machines, and not a foundry foreman who is not familiar with centrifugal casting.

CONCLUSION

27. In conclusion, we again urge caution. Do not look upon centrifugal casting as a panacea for casting problems. Centrifugal casting and centrifuging have their field, but there are still the majority of castings which must be made statically. No matter how carefully we plan, build and operate, we can always expect a slip-up somewhere. Once we had a cover lift off a large casting being poured vertically. The metal sprayed out radially, leaving a highwater mark all around the vicinity, and sent two men to the hospital. In another case, not at this plant, a vertical shaft bent and, as the machine twirled, the metal was thrown out of the cover hole. At the same time, the ladle was held away by the rapid blows of the mold. But when the speed dropped, the ladle swung in, and was promptly knocked over.

28. In our most serious accident, a 900-lb. die broke. The machine was not damaged, but the half-ton guard was thrown against a man with such force that he was knocked across to the next machine, where the cover had just been taken off a red hot casting weighing 500 lb. The man is still with us, although he was hospitalized for nearly three months with both jaws broken and his stomach burned. We cannot be too cautious. The old adage that familiarity breeds contempt is sadly true in the case of centrifugal equipment. We can carefully plan our operations, but no one as yet has solved the human equation.

DISCUSSION

Presiding: A. K. HIGGINS, Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Co-Chairman: NATHAN JANCO, Centrifugal Casting Machine Co., Tulsa, Okla.

T. R. WALKER, JR.[1]: At what section of the casting is the centrifugal force ordinarily determined?

MR. WEBER: In determining the pressure in centrifugal work, we figure about 45 to 55 G's. It is not necessary to have that much force in centrifuging, 10 to 20 G's being considered sufficient. The force itself is generally taken arbitrarily at the center of mass. It is my opinion that the center of mass is probably the average cross section of the effect of the entire piece.

MR. WALKER: Are you talking about centrifuging or centrifugal casting?

MR. WEBER: Either one.

MR. WALKER: In centrifugal casting, if there is a heavy section, is it not necessary to determine the speed from the inside diameter rather than from the mean diameter? Is not the problem to hold the metal up at the smaller diameter?

MR. WEBER: If we figure approximately 55 G's at the radius of gyration, that will give us approximately 1500 ft. per min. at the radius of gyration for a 4-in. radius. There will be plenty of speed to hold the metal up. As far as I know, it does no good to overrun the speeds on the machine. An extremely high rate of speed will not increase the density of the casting.

CO-CHAIRMAN JANCO: In vertical true centrifugal castings, the taper of the inside diameter is a function of the speed. It is just a mechanical process. Seventy-five G is approximately equivalent to a slope of the inside diameter of ⅛-in. per ft.

[1] Warren Pipe Co. of Mass., Inc., Everett, Mass.

The Influence of the Centrifugal Process on the Physical Properties of Some Non-Ferrous Alloys

By W. W. Edens* and J. F. Klement*, Milwaukee, Wis.

Abstract

This paper presents the data obtained in tests made with various non-ferrous alloys, sand cast, centrifugally cast and forged. The authors consider densities, chemical analyses, microstructures and tensile test values in their study. There are photomicrographs to show the variations in the microstructure and tables to show the differences in analyses and physical properties. The authors arrive at definite conclusions regarding densities, chemical analyses, grain sizes and physical properties.

Introduction

1. The purpose of this paper is to discuss the influence of the centrifugal casting process on the metallurgical properties of various non-ferrous copper base alloys as compared to other methods of manufacturing, primarily sand casting. The discussion and data are limited to true centrifugal castings and do not include the method more generally known as the centrifuge process.

2. Previous workers have described centrifugal processes and design, but little information has been available on the metallurgical considerations of copper base alloys as they are influenced by the centrifugal process.

3. The data, which is to be reported from the metallurgical aspect, include densities, chemical analyses, microstructures and tensile test values.

Testing Procedure

4. The procedure followed in testing was as follows:

(1) All test material was taken from the same melts for each type of composition and alloy. Positions of physical tests and chemical samples are shown in Fig. 1.

(2) All tensile testing was performed in accordance with A.S.T.M. (E8-40T). Yield strengths were taken at 0.5 per cent elongation under load. An extensiometer sensitive to 0.0001 in. was used.

(3) Much of the data was taken from production records with isolated cases, however, being taken from special heats.

(4) All photomicrographs were taken at 100 diameters.

*Chief Metallurgist and Asst. Chief Metallurgist, respectively, Ampco Metal, Inc.

Note: This paper was presented at a Centrifugal Casting Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, New York, April 27, 1944.

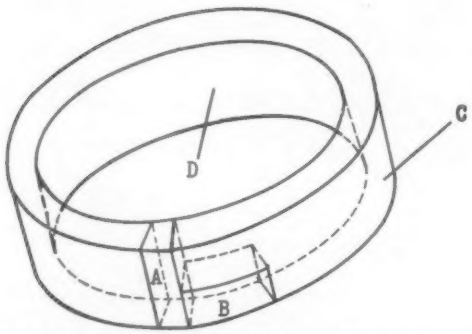


FIG. 1—VIEW OF TYPE OF CASTING USED FOR TESTS. A—SECTION OF RING USED FOR VERTICAL TEST BAR. B—SECTION OF RING USED FOR HORIZONTAL TEST BAR. C—SECTION DRILLED FOR CHEMICAL ANALYSIS OF OUTSIDE SURFACE. D—SECTION DRILLED FOR CHEMICAL ANALYSIS OF INSIDE SURFACE.

DISCUSSION

5. In considering the centrifugal process, in which molten metal of various types and compositions is poured into a rotating mold, it is logical to suspect that certain of the metallurgical properties in the product may be favorably or unfavorably affected. The most significant properties and those which the authors wish to evaluate herein are density, variation in chemical analyses at various points, metallographic structures and tensile test values.

Density

6. Relative densities of the various alloys tested for sand and centrifugally cast material are shown in Table 1. As a matter of fact, when material is properly produced there is little difference in density between sand cast, centrifugally cast, chill cast, and forged material (50 per cent reduction), as is shown in Table 1. Actual density or weight per unit volume varies more with composition than it does with method of fabrication, as witnessed by the fact that in an aluminum bronze alloy conforming to QQ-B-67la, class C, the density with 10.5 per cent aluminum is 7.51, and with 11.2 per cent aluminum it is 7.40.

7. Perhaps the greatest factor influencing density in any casting is the establishment of directional solidification and proper feeding ahead of solidification. The macrostructure shown in Fig. 2 is an excellent example of a section of a centrifugal casting of Navy "M" composition, in which proper directional solidification did not occur, resulting in the densities as shown. The centrifugal process will, by its very nature, if properly controlled, produce more uniform densities than can be achieved in static castings. The molten metal flows against the mold wall under relatively high pressure, thus assuring good thermal conduction to the mold surface and the abstraction of heat at rates which can be varied with mold material at that surface, thus initiating

Table 1

Specific Gravities of Various Non-Ferrous Alloys (One-In. Sections)

Specification	Specific Gravity at 20° C. — Sand Cast	Centrifugally Cast	Chill Cast	Forged
S.A.E.-68B	7.58	7.59		
QQ-B-671a, Class A	7.67	7.66		
QQ-B-671a, Class C	7.48	7.50		
QQ-B-726a, Class A	8.29	8.28		
QQ-B-726a, Class C	7.72	7.71		
Navy "M"	8.86	8.90		
Navy "G"	8.92	8.90		
85-5-5-5	8.91	8.90		
72 Cu, 22 Pb, 6 Sn	9.28	9.29		
98 Cu, 1.5 Ni, 0.5 Be	8.82	8.85		
QQ-B-671a, Class C	7.47	7.48	7.47	7.48

progressive solidification and forcing impurities, gas and oxides ahead of crystallization.

Chemical Analysis

8. Table 2 shows the chemical analysis of materials used in these tests, including those samples taken from outer diameters and inner diameters of test rings, as shown in Fig. 1.

9. In solid solution type alloys, there seems to be no effective difference in

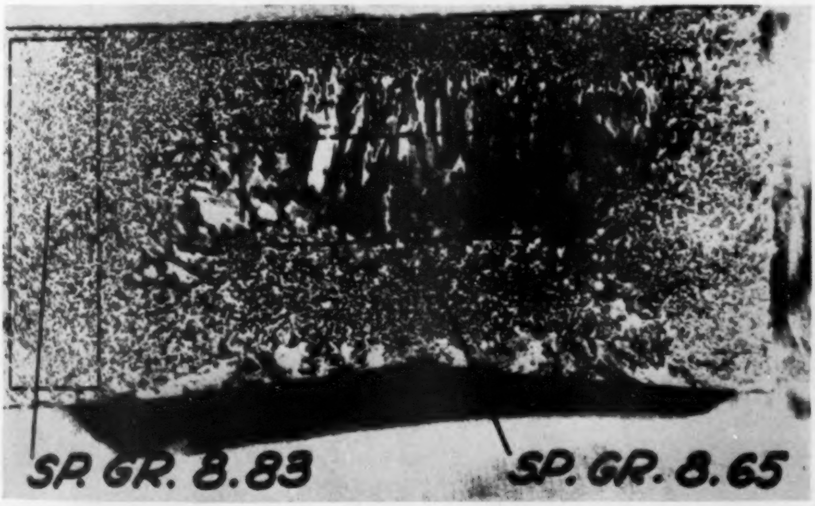


Fig. 2—Macrostructure of a Section of a Centrifugal Casting of Navy "M" Composition in Which Proper Directional Solidification Did Not Occur. Note Difference in Density.

Table 2

VARIATIONS IN ANALYSES OF CENTRIFUGAL CASTINGS

Specifications	*Specimen Position**	Elements									
		Cu	*Al*	*Fe*	*Ni*	*Mn*	*Sn*	*Pb*	*Zn*	*P*	*Be*
S.A.E.-68B	I.D.	89.02	10.00	0.86	0.10	0.02					
	O.D.	89.01	9.98	0.88	0.09	0.02					
QQ-B-671a, Class A	I.D.	87.16	8.86	2.86	0.12	0.03					
	O.D.	87.09	8.88	2.90	0.12	0.03					
QQ-B-671a, Class C	I.D.	85.53	10.46	3.68	0.33	0.02					
	O.D.	85.63	10.39	3.57	0.32	0.02					
QQ-B-726a, Class A	I.D.	58.70	1.01	1.10		0.23	0.12		Bal.		
	O.D.	58.66	0.96	1.06		0.22	0.09		Bal.		
QQ-B-726a, Class C	I.D.	61.63	5.05	2.68	0.04	2.40			Bal.		
	O.D.	61.62	5.07	2.78	0.05	2.43			Bal.		
Navy "M"	I.D.	88.29		Trace	0.25	0.01	6.83	1.32	Bal.	0.02	
	O.D.	87.80		Trace	0.24	0.01	6.93	1.62	3.25	0.02	
Navy "G"	I.D.	87.20		0.06	0.26		7.86	0.11	3.46	0.02	
	O.D.	87.06		0.06	0.28		7.96	0.13	3.41	0.02	
72 Cu, 22 Pb, 6 Sn	I.D.	72.04		0.01	0.72		4.97	22.34			
	O.D.	70.25		0.01	0.72		5.13	23.81			
98 Cu, 1.5 Ni, 0.5 Be	I.D.	98.13		0.02	1.30	0.01					0.44
	O.D.	98.17		0.02	1.25	0.01					0.45

*Specimen for analyses taken from inside surface and outside surface (Fig. 1).

analysis between the outer diameter and the inner diameter, even in exceptionally heavy wall thicknesses. However, in alloys having separable components, such as high lead alloys, some difference will be found between the outside diameter and the inside diameter, with the lead, due to its heavier weight, tending to go to the outside under centrifugal force. However, this difference can be greatly minimized by the use of proper mold materials and designs, although certain limitations will always remain in heavy wall thicknesses or irregular sections.

Metallographic Structures

10. Nothing can illustrate the benefits of rapid and progressive solidification as well as the structure of an alloy as disclosed by the microscope. Photomicrographs taken at 100 diameters help to bear out the fact that good values are obtained from a well solidified section of metal. This controlled solidification responds differently under various conditions, such as variations in mold materials and temperatures. Figure 3 shows an aluminum bronze alloy, QQ-B-67la, class A, in three conditions: sand cast, centrifugally cast and forged. Alpha is present in a beta matrix. The sand cast material, where practically no chill existed, displays almost 100 per cent alpha, while beta increases as the rate of chill increases from below the solidification temperature.

11. Figure 4 shows an aluminum bronze alloy SAE-68B (as cast). The size of alpha in the cast condition of this alloy is controlled by the cooling rate from approximately 1700° F. The forged sample of this alloy definitely shows that the material was chilled by the forging die. The centrifugally cast materials, when considering microstructures from the cast state, are more easily controlled for the smaller sizes of castings than either forged or sand cast material. This is true because of the flexibility of die materials insofar as heat extraction rates are concerned. However, limitation of mold design offers a drawback to its general use.

12. Figure 5 shows QQ-B-67la, Class C, another aluminum bronze alloy. The cooling rate from solidification in this case made the centrifugal cast material finer, in both grain size and alpha particles, than either the sand cast or forged material.

13. Navy "M," 46-B-8G alloy, can be seen in Fig. 6. The sand cast and the centrifugally cast structures differ greatly in this material. It is common in tin bronze to have such a difference in the photomicrographs, especially in small sections. This difference does not exist as pronouncedly in sections of over 2 in., as is shown in Fig. 6.

14. When lead appears in alloys, chilling helps to keep the lead globules small and evenly distributed if the sections are not too large. Figure 7, which is 46-B-23C (85-5-5-5) alloy, represents a casting of equal cross section for both the sand and the centrifugal material. The distribution of lead can very easily be seen in both specimens.

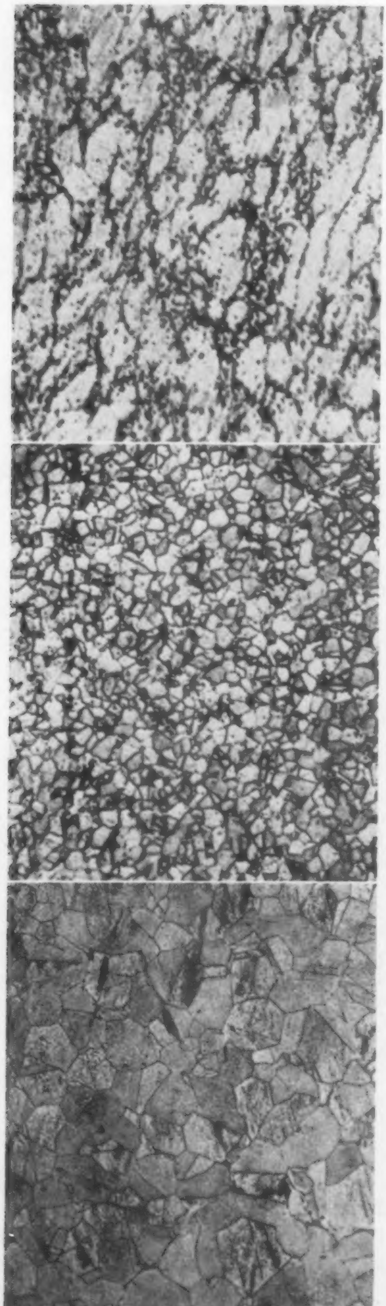


FIG. 3—PHOTOMICROGRAPH OF QQ-B-671A, CLASS A, MATERIAL. LEFT—SAND CAST. CENTER—CENTRIFUGALLY CAST. RIGHT—FORGED. MAGNIFICATION X100.

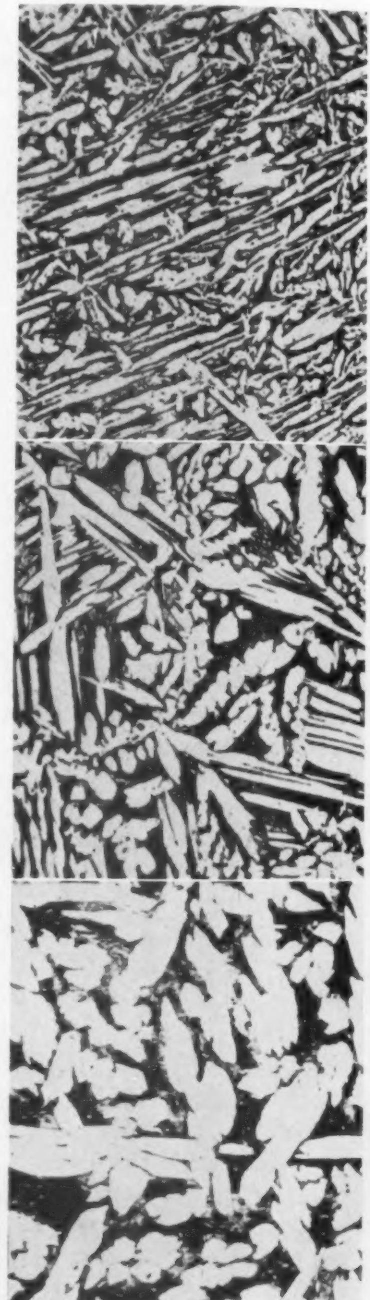


FIG. 4—PHOTOMICROGRAPH OF S.A.E.-68B MATERIAL. LEFT—SAND CAST. CENTER—CENTRIFUGALLY CAST. RIGHT—FORGED. MAGNIFICATION X100.

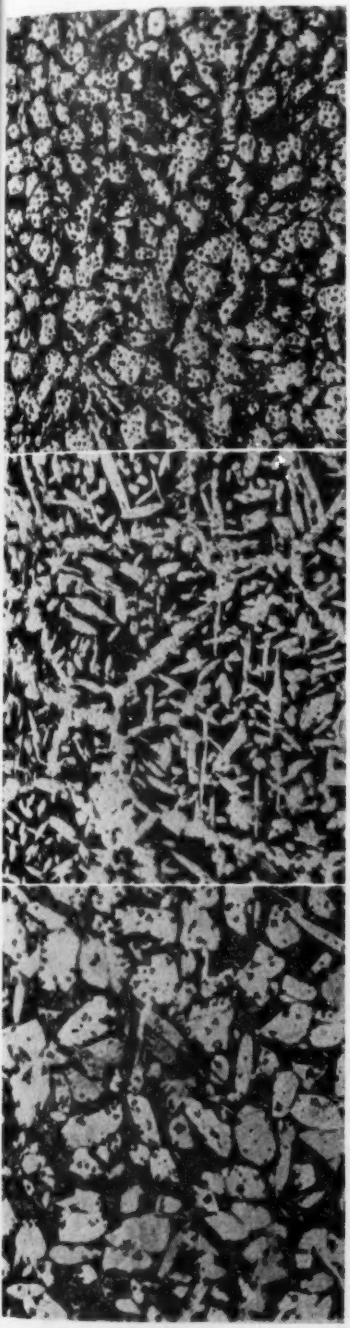


FIG. 5—PHOTOMICROGRAPH OF QQ-B-671A, CLASS C, MATERIAL. LEFT—SAND CAST. CENTER—CENTRIFUGALLY CAST. RIGHT—FORGED. MAGNIFICATION X100.

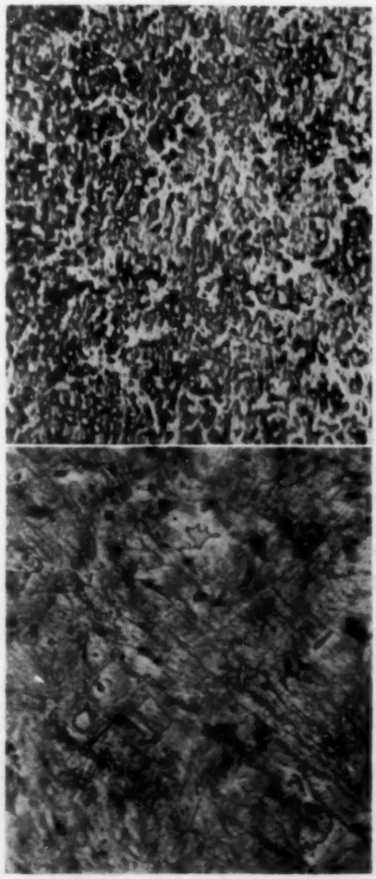


FIG. 6—PHOTOMICROGRAPH OF NAVY "M" (46-B-8G) MATERIAL. LEFT—SAND CAST. RIGHT—CENTRIFUGALLY CAST. MAGNIFICATION X100.

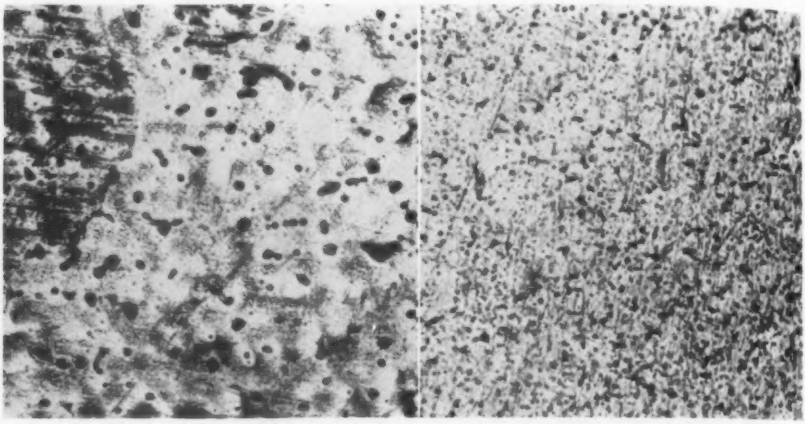


FIG. 7—PHOTOMICROGRAPH OF 46-B23C (85-5-5-5) MATERIAL. LEFT—SAND CAST. RIGHT—CENTRIFUGALLY CAST. MAGNIFICATION X100.

15. When the tin increases (Fig. 8) as in alloy 88-10-2 (46M-6G), a marked decrease in the size of the delta network can be seen in the centrifugal casting structure as compared to the structure of the sand cast material. The fine distribution of delta network helps to increase the hardness of the centrifugal casting.

16. Another example of grain and phase refinement can be seen in Fig. 9. Here a low tensile manganese bronze alloy of the QQ-B-726a, class A type, shows a comparison between a sand cast, a centrifugally cast, and a forged material. The centrifugally cast structure is chilled and is finer than the sand cast material. However, the forged material, due to being chilled in forging,

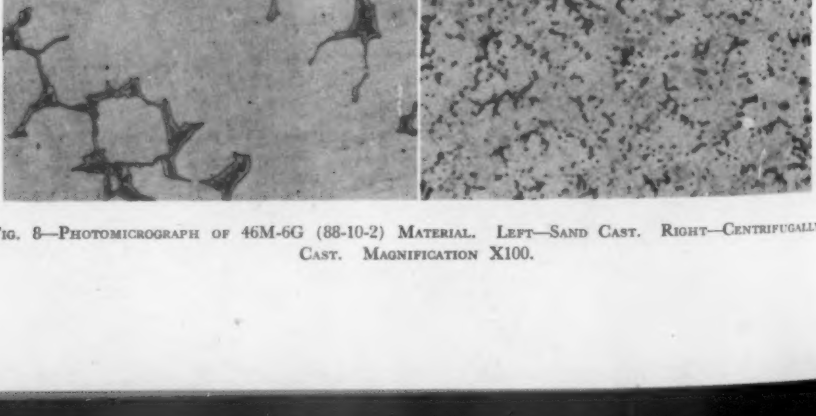


FIG. 8—PHOTOMICROGRAPH OF 46M-6G (88-10-2) MATERIAL. LEFT—SAND CAST. RIGHT—CENTRIFUGALLY CAST. MAGNIFICATION X100.

has smaller alpha particles but larger grains. The structure of the centrifugally cast material was superior in physical properties to both the sand cast and the forged materials. This was true only because of the desired distribution and size, of both constituent and grain, which was obtained.

17. The same condition as is shown in Fig. 9 exists in Fig. 10, which shows a high tensile manganese bronze alloy of the QQ-B-726a, class C, type.

Tensile Test Properties

18. A comparison of physical properties between sand and centrifugally cast alloys, as shown in Table 3, will further bring out the intrinsic value of controlled directional solidification and the desirable metallographic structures which are native to properly produced centrifugal castings.

19. Variations in physical properties can exist in the same casting when the centrifugal process is used. This variation can exist from the outside to the center in a large casting, or can exist, but not very noticeably, in the vertical and horizontal directions as related to the axis of rotation when casting a regular cylindrical-type casting (Table 4). This variation in the physical properties of centrifugally cast material is very small when compared to the variation in wrought material, where the directional properties are pronounced and, frequently, are adverse for the application. Table 4 shows an aluminum bronze material having this condition.

Table 3

COMPARISON OF PHYSICAL PROPERTIES OF CASTINGS—1½-IN. SECTIONS—SAND AND CENTRIFUGALLY CAST

Specification	*Method of Casting**	*Tensile Strength, psi.*	*Yield Strength, psi.*	*Elongation in 2-in., per cent*	*Reduction of Area, per cent*
S.A.E.-68B	S.C.	71,000	28,000	30.0	31.0
	C.C.	77,600	31,775	39.3	33.9
QQ-B-671a, Class A	S.C.	79,200	28,900	39.8	39.5
	C.C.	87,600	32,200	40.1	42.5
QQ-B-671a, Class C	S.C.	83,600	35,200	12.3	11.2
	C.C.	97,100	37,800	16.7	17.3
QQ-B-726a, Class A	S.C.	71,700	26,400	30.3	30.1
	C.C.	77,500	33,200	37.2	38.0
QQ-B-726a, Class C	S.C.	111,500	70,500	15.0	19.5
	C.C.	120,250	73,300	22.6	28.6
Navy "M," 46-B-8G	S.C.	41,430	21,140	39.3	32.5
	C.C.	48,775	21,200	60.6	40.1
Navy "G," 46-B-5H	S.C.	46,675	23,900	24.8	27.8
	C.C.	51,500	27,100	55.0	53.5
46-B-23C	S.C.	35,680	19,460	24.4	22.7
	C.C.	51,250	24,800	42.0	41.0

*S.C.—Sand Cast, C.C.—Centrifugally Cast.

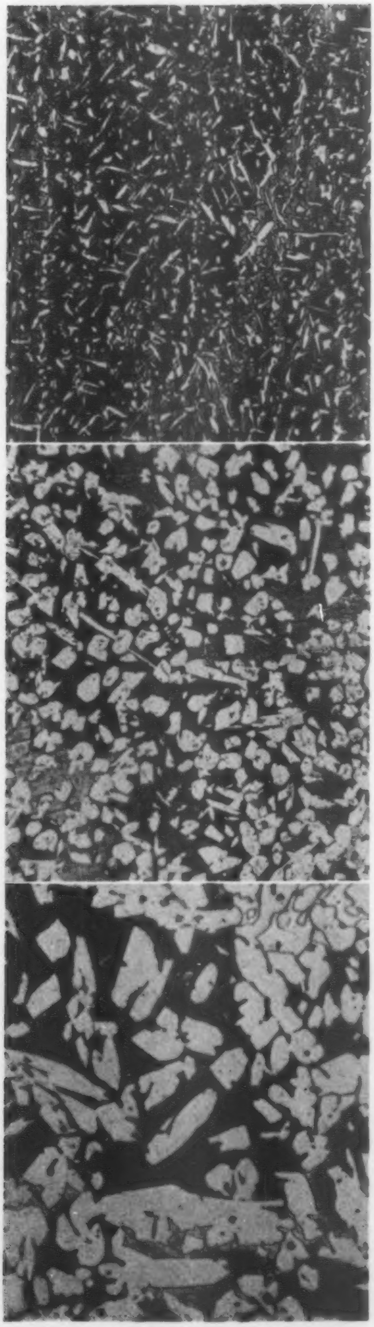


FIG. 9—PHOTOMICROGRAPH OF QQ-B-726A, CLASS A, MATERIAL. LEFT—SAND CAST. CENTER—CENTRIFUGALLY CAST. RIGHT—FORGED. MAGNIFICATION X100.

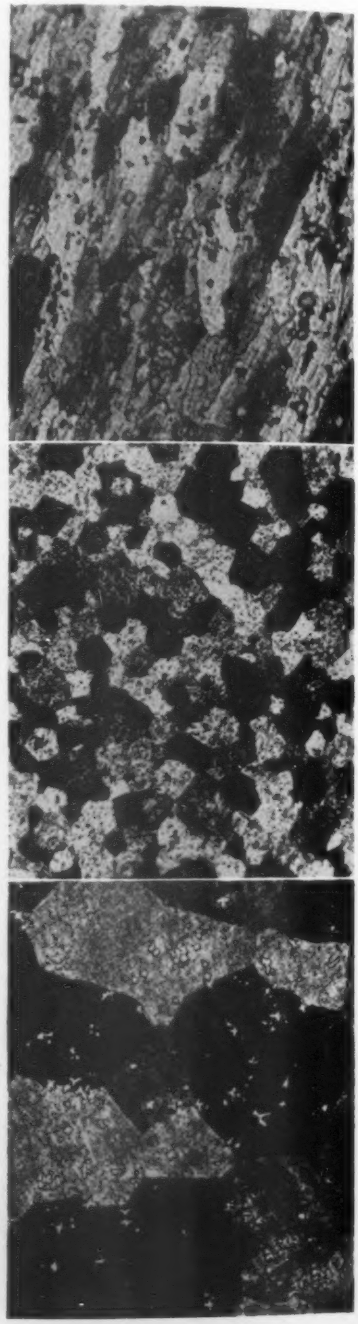


FIG. 10—PHOTOMICROGRAPH OF QQ-B-726A, CLASS C, MATERIAL. LEFT—SAND CAST. CENTER—CENTRIFUGALLY CAST. RIGHT—FORGED. MAGNIFICATION X100.

Table 4

VERTICAL AND HORIZONTAL PHYSICAL PROPERTIES

Specification *Centrifugal (36-in. Dia., 4-in. Section*)*		*Vertical*	*Horizontal*
QQ-B-671a, Class C	Tensile strength, psi.	91,000	87,000
	Yield strength, psi.	37,500	37,000
	Elongation, per cent	13.5	11.0
	Reduction of area, per cent	13.0	10.7
QQ-B-726a, Class C	Tensile strength, psi.	122,000	114,000
	Yield strength, psi.	67,500	67,000
	Elongation in 2-in., per cent	23.0	21.0
	Reduction of area, per cent	22.7	23.4
Navy "M"	Tensile strength, psi.	50,500	48,000
	Yield strength, psi.	27,500	27,500
	Elongation in 2-in., per cent	26.0	23.0
	Reduction of area, per cent	24.0	24.0
Wrought (4-in. Dia.)			
QQ-B-666, Grade B	Tensile strength, psi.	78,000	82,000
	Yield strength, psi.	32,500	36,500
	Elongation in 2-in., per cent	21.5	35.0
	Reduction of area, per cent	22.3	37.0

CONCLUSION

20. No appreciable difference exists in the densities between a good sand cast and a centrifugally cast material. Discrepancies which exist can be attributed more often to variations in chemical analyses than to densities when comparing sound sand cast and centrifugally cast material. Generally, it may be said that a centrifugal casting has greater density than a sand casting when the casting is considered as a whole, and then only because of the feeding difficulties encountered in the sand casting. Where sound metal is provided by either method, there is no appreciable difference in density.

21. In ordinary sections, no noticeable variation in chemical analyses exists in solid solution type alloys. However, alloys which include lead will show some variation in chemical analyses between the outside and inside wall surfaces. This variation will increase as the wall thickness and percentage of lead in the alloy increases. Normally, no change in the usual analysis of any specific alloy will have to be made for the purpose of casting centrifugally.

22. Grain sizes for the same sections are finer in centrifugal castings than they are in static castings. This is due, almost entirely, to controlled rapid solidification, which is an integral part of the centrifugal process.

*Vertical specimens were taken from Section A (Fig. 1) and horizontal specimens were taken from Section B (Fig. 1).

23. The physical properties obtained by the centrifugal process are approximately 10 per cent greater than those obtained by the static method, for equivalent sections. However, the specific improvement will vary with the alloy and, in some cases, certain properties will be doubled, as is indicated in Table 3. In general, tensile strengths, elongations, and reductions of area are more favorably affected than the yield strength properties of an alloy.

24. Small differences in physical properties exist in the vertical and horizontal planes, as is frequently found in sand castings. However, this difference is insignificant as compared to that of the directional properties frequently found in some wrought materials.

DISCUSSION

Presiding: A. K. HIGGINS, Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Co-Chairman: NATHAN JANCO, Centrifugal Casting Machine Co., Tulsa, Okla.

M. C. ROWLAND[1]: What are the differences in yield strengths and elongation of samples taken from the outside and inside diameters of a 20-in. casting having an inside diameter of 3 in.?

MR. KLEMENT: Generally speaking, it will depend upon several factors; the first is the alloy and the second is the die material. In tin bronzes we could expect a reduction in elongation and tensile values of about 30 per cent. The yield strength will not vary too much. However, in aluminum bronze or manganese bronze alloys the reduction in physical properties will not be as high (as in tin or lead bronze alloys).

D. BASCH[2]: Have you ever considered the elastic limit? Not the yield strength, because the yield strength is not a complete indication of the elastic strength of the material. On the stress-strain curve, we may find the curve leaving the line long before the yield strength is reached.

MR. KLEMENT: No, we have not investigated the elastic limit. We appreciate the fact that elastic limits cannot be compared with yield strengths. However, most of our non-ferrous specifications call for yield strengths in either 0.5 per cent elongation under load or the 0.2 per cent offset method.

D. E. BEST[3]: Were these centrifugal castings made against sand?

MR. KLEMENT: No, in most cases our work was done against carbon.

MR. BEST: Was there any cooling from the interior of the centrifugal casting, or was it permitted to cool normally?

MR. KLEMENT: No method was used to cool the castings from the interior. They were cooled normally.

MEMBER: Is the temperature of the mold established according to the wall thickness of the casting?

MR. KLEMENT: Not exactly. More depends upon the mold material than the thickness of the casting. In casting against copper, we would use a higher pouring temperature and have a hotter mold temperature than in casting against a sand liner. The type

[1] General Electric Co., Schenectady, N. Y.
[2] General Electric Co., Schenectady, N. Y.
[3] Bethlehem Steel Co., Bethlehem, Pa.

of casting to be poured, and by this we mean if it is a shape or just a cylindrical bushing, probably influences the mold temperature more than does the thickness of the casting.

MEMBER: What was the section thickness of the chemical and physical samples?

MR. KLEMENT: The section thickness of the chemical sample was approximately 3 in. The section thickness for the physical samples was the same when comparing vertical and horizontal tests. However, when we compared sand and centrifugal, tests were made on approximately 1½-in. sections.

MEMBER: Were any tests made casting against sand and against carbon?

MR. KLEMENT: Yes, we made some tests against sand and against carbon, and we can say that the properties of the metal cast against a sand liner are not quite as good as those cast against carbon.

MEMBER: How were the carbon molds made?

MR. KLEMENT: They were machined from scrap electrodes.

MEMBER: What would limit the size of casting? Could a propeller be cast in carbon?

MR. KLEMENT: It has been our experience that castings such as propellers and shapes are made in cores more easily than in carbon molds. It seems that it is too expensive to machine carbon into molds for shapes because carbon breaks rather easily when making shapes.

MEMBER: Would there be any objection to using powdered graphite?

MR. KLEMENT: No, none that we can say. Of course, it would seem to us that the cost would be rather high unless a production setup could be obtained.

MEMBER: Did you compare the relative merits of using a sand mold and a cast iron mold for your casting production?

MR. KLEMENT: Yes, we have found that the type of mold material to be used depends largely upon the number of castings to be made and the alloy to be used. If we were to have a long-time job, we would use steel, copper or cast iron molds.

MEMBER: Would the use of metal molds affect the pouring temperature?

MR. KLEMENT: Yes, higher pouring temperatures are used for metallic molds than for non-metallic molds. We use approximately 100 degrees higher pouring temperatures for centrifugal castings than we do for static castings.

MEMBER: Is there a chill effect when the metal comes in contact with the mold?

MR. KLEMENT: Yes, there is. However, this depends a great deal upon the type of material used for the mold. Copper will chill, as we all know, more easily than a sand liner.

MEMBER: What is the depth of the chill? Is not the solidification, depending upon the wall thickness, quite rapid?

MR. KLEMENT: Again we must say that the depth of chill depends upon the die materials and mold materials and the pouring temperatures used. However, we can say that in some cases the solidification, depending upon the wall thickness, is almost instantaneous.

MEMBER: Would that rapid solidification hurt the structure or tensile strength of the material?

MR. KLEMENT: No. According to our investigation and the work we have done, we find that the rapid solidification increases the tensile strength and helps to decrease the grain size. It also slightly increases the yield strength. The rapid solidification will also help the distribution of lead.

MEMBER: Is the metal structure more dense right at the point where the metal comes in contact with the mold? Are most of the castings cast to size?

MR. KLEMENT: There is a very thin section, approximately 1/16-in., which is very fine. This thin section has a definite chill and the structure here is more dense than throughout the casting. Most of these castings were not cast to size. They have approximately ⅛-in. finish on the outside diameter.

G. J. LE BRASSE[4]: Have you taken macrostructures on the same sections from which you obtained the tensile strength bar results?

MR. KLEMENT: Yes, we have done this. In fact, in production when we start a new job we take macrostructures of the sections on the first few castings to see how well we have solidified the material.

MR. LE BRASSE: In other words, good physical properties on spun cast material presuppose uniform grain size in the macrostructure.

MR. KLEMENT: Yes, we would say that. If we have a dense structure, in other words a very solid material, we naturally should have good tensile properties. In most centrifugal castings of the type we have shown, proper solidification is more easily obtained than in static castings and, therefore, tensile strengths and macrostructures are better than in a static casting.

MEMBER: How do cast iron molds stand up and do you coat them with any material?

MR. KLEMENT: The cast iron molds stand up very well, depending upon the alloys being cast. The alloys used also determine whether or not the mold is coated. For instance, we have difficulty in casting phosphor bronzes against steel molds unless the mold is coated.

MEMBER: Are the molds coated in all cases?

MR. KLEMENT: No. In some cases the molds are just preheated with a torch. In other cases, depending upon the alloys used and the mold materials, a coating is used.

H. J. ROAST[5]: In casting a leaded bronze alloy, we found that the mold coating was an absolutely essential feature. Extreme care was necessary, not only in the selection of the coating but in its application.

---

[4] Federal Mogul Corp., Detroit, Mich.
[5] Canadian Bronze Co., Montreal, Que., Canada.

Centrifugal Casting of Non-Ferrous Metals

By I. E. Cox*, St. Louis, Mo.

A constructive review of problems relating to centrifugal casting of non-ferrous bearing metals, presented by the author and his co-workers as a contribution to the development of the centrifugal casting process. One of the interesting features of the paper, which was originally presented at the War Production Conference, January 14, 1944, in New York, is the research approach toward developing a mechanized method of centrifugal casting production.

CENTRIFUGAL casting of non-ferrous metal, in its present state of development, is rather an art than a science when we consider that art is a knowledge made efficient by skill, and science is the recorded and systematized application of that knowledge. The reduction of the art to the science is essential to the improvement and perpetuation to this process of casting, and this is especially true in the case of non-ferrous metals.

We find our foundries are fertile fields of unexplored art. Our melters, our molders, our coremakers and even our foundry laborers are the performers that the foundry research workers have to observe if their art is to be reduced to science. The secrets of these craftsmen are difficult to uncover.

The company, with which the author is associated, believes the centrifugal casting problem should be attacked on this basis. In the production of a casting, the art should first be reduced to a science and absolute systematized knowledge of the required details given to engineers, who can then develop equipment that will control such critical functions as time, temperature, and rate of change of temperature and other technical details to where they will not be subject to the discretionary judgment of any individual.

Inherently, the process will thus be mechanized insofar as possible, thereby reducing labor required to a minimum. Quality will be improved and uniformly maintained.

Research Entails Equipment

To successfully carry on such research and engineering development for centrifugal casting, we had to acquire a full complement of laboratory apparatus and instrumentation, including precision temperature indicating and recording equipment, photo microscope and accessories, x-ray and the necessary apparatus for determining all required physical characteristics and a chemical laboratory for rapid and accurate quantitative determinations. Special machines had to be developed. Pilot models of the production units were laboratory built to save time.

We find we now need a small engineering department machine shop with representative machine tools of each class. Our experience indicates incomplete facilities necessitate extension of developmental programs, with results that are "too little and too late" to keep abreast of war impacted demands for new and better materials that competitors will provide if we do not.

Our first centrifugal casting problem involved a bearing lined

*Chief Engineer, National Bearing Metals Corp.

Note: This paper was presented at a Centrifugal Casting Symposium Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 27, 1944.

with a babbitt which had to be centrifugally applied to secure the required bond and a dense sound lining. This metal was a calciated lead inhibited against corrosion by the necessary tin content. It had to be melted and poured in an atmosphere with no oxygen content.

Several of our most skilled babbitt handlers were drafted for research observation, and the bearings were processed using a lathe as a spinning machine where all functions were hand controlled. Pouring temperature, rate of pour, control of cooling rate after pouring, and methods of applying controlled atmosphere inside of the bearing to eliminate any oxygen content in the bearing bore during pouring operation were explored.

DESIGN OF BABBITTING UNIT

After all these details were studied, the babbitting unit (Fig. 1) for centrifugal casting of these bearings was designed as follows:

Raw natural gas was used as a neutral atmosphere under which the metal was melted in a covered pot designed for immersion unit heating. An elevator arrangement was provided to charge this melting pot, ingot at a time, without disturbing the oxygen free atmosphere on the pot.

A valve was provided in the bottom of the pot, operated by an air cylinder and controlled by a magnet valve. The valve opening was pre-set by a hand operated screw to control the rate of flow, and the amount of metal was controlled by a vacuum tube-type electric timing relay, which gave automatic control on the amount of metal and the rate of flow poured in each bearing.

This spinning machine was constructed similar to a lathe, having two spindles, one in the fixed head and one in a moving head mounted on a carriage. The fixed head was placed adjacent to the bottom pour pot to minimize the travel of the molten metal, and the spout of the bottom pour pot ran through a hollow spindle of this fixed head. The movable head, mounted on the carriage, was driven by a variable speed DC motor direct-connected and supported on the carriage. The carriage movement was controlled by an air cylinder to clamp the bearing to be lined between the easily replaced adapters mounted on the spindles of the heads.

The cooling of the rotating bearing, after being filled with the proper amount of molten metal, was controlled by a timed exposure to a blast of aerated water vapor directed through a distributing head placed between the splindles. City water and a motor driven blower were used as the sources of air and water.

A raw gas line was provided through the spindle of the fixed head to purge the interior of the bearing of air by displacement with raw natural gas.

AIRCRAFT SPECIFICATION PRODUCTION

All compressed air, water and gas lines were controlled by magnet valves. A canopy cover, air cylinder operated with magnet valve control was arranged to automatically open and close at the proper time, as protection against the possibility of a hot metal leak during the pouring operation and to catch the cooling water so that it could be drained into a sewer.

It was also found necessary to put a ring gas burner around each of the two heads that contacted the bearing to heat them up after the

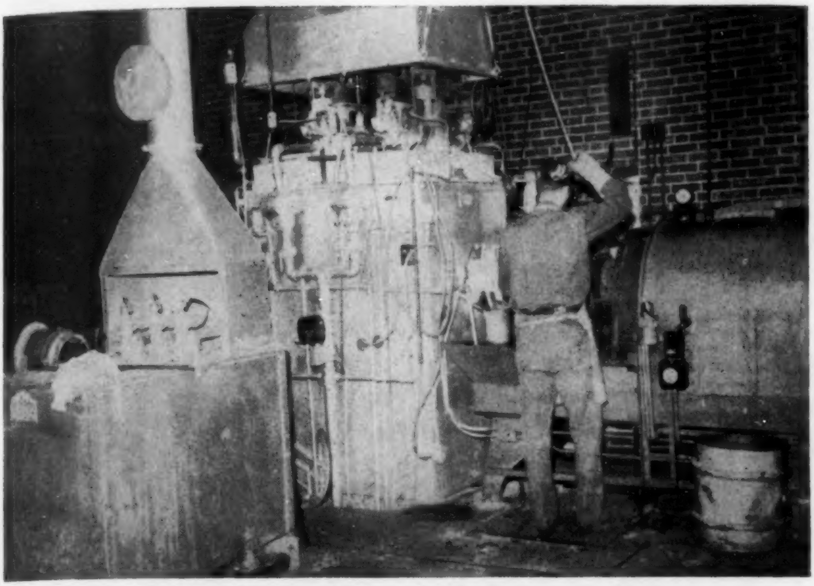


Fig. 1—Centrifugal Babbitting Unit.

completion of a chilling cycle for the reception of the next pre-heated bearing. These ring burners were provided with electric ignition and magnet valve control.

Protection was provided for the operator by a treadle switch, so arranged that when anybody was in front of the machine with the cover retracted, the electric ignition was shut off and the gas burners extinguished.

All of the functional operations of this machine were reduced for electrical control. By proper application of limit switches, timing relays, and electrical interlocks, automatic and instantaneous functional sequence was secured.

All an operator has to do is place a tinned, pre-heated bearing between the spindles, operate a valve to its running position and step on an instantaneous contact starter switch. The entire operation of purging, lining and cooling the bearing is then taken care of automatically.

When the cycle was completed and the machine brought to rest, the cover of the machine was automatically withdrawn ready for the removal of the lined bearing and the insertion of the next bearing to be processed.

It took approximately one year to build this machine, including development time. It requires only one man to operate it, as compared with four men for the unit it superseded. Production was increased 400 per cent per unit.

Our next centrifugal casting project was the development of equipment to produce a gun bronze cam bearing blank to an aircraft specification that required individual x-ray of each casting.

We were practically forced to cast this piece centrifugally due to

the fact that the desired quality could not be produced statically cast in sand. Our Jersey City plant started work on this problem. Due to the fact that we had no engineering organization or laboratory equipment at Jersey City, it was more difficult to handle the job long-distance so the job was taken to St. Louis.

All published work on prior art was reviewed carefully, but was found confusing, necessitating some preliminary investigation of fundamentals. Both a horizontal and vertical spindle machine were set up for experimental purposes. The first problem was to find out what determined the proper axis of rotation for casting. We had to find what type of mold and what mold material was best suited.

On the heels of this problem, we had to find a mold wash. The exact pouring temperature had to be ascertained as well as the speed and power requirements.

We quickly found that the axis of rotation is a matter of convenience of getting the metal in the mold, and otherwise does not affect the casting, except that in long castings in the form of bushings cast with the spindle approaching a vertical axis, that excessive speeds were required to get the metal to climb and to prevent excessive taper in the bore.

DETERMINING POWER REQUIREMENTS

After careful observation we arrived at the conclusion that higher quality could be secured by casting short bushings singly on a vertical spindle rather than in tub form.

For mold material we tried baked sand cores, then carbon and then gray iron. The chill effect of the gray iron mold produced the desired fine grain structure and physical qualities that were required for this piece. The carbon came second.

The sand cast by the centrifugal process was an improvement over static sand casting, but left a lot to be desired. An open grained molybdenum gray iron mold produced the best castings, withstood heat shock successfully and gave the longest life. We are still experimenting with several types of iron.

The larger molds are subjected to the most severe conditions, and our experience indicates the experimental molds furnished by a brake shoe show promise of being most satisfactory.

Various mold washes were experimented with, which are necessary to prevent the molten bronze from burning in the mold surface, and to facilitate the removal of the casting from the chill mold.

Where rapid chilling is essential, a mixture of colloidal lead and graphite sprayed in the mold has proved very satisfactory. Where a slower chill rate can be tolerated, a mixture of bentonite and silica flour has worked out well.

Melting practice and pouring temperatures are far more critical for centrifugal chill casting than are commonly practiced in sand foundries. Here the services of the trained metallurgist are necessary to determine whether the flame shall be oxidizing or reducing, and to what degree, especially if crucible furnaces are used for melting.

This requires frequent Oerstad tests of the products of combustion from these furnaces to maintain

proper burner adjustment. It is beyond the scope of the assigned subject to go into detail in this matter.

Spinning speeds were experimented with, and it was found that the best results could be produced from 1100 to 1300 ft. per min. peripheral speed on the interior mold wall surface.

In general practice, in centrifugal chill mold casting process on vertical spindles, the height of a mold was limited to its diameter. With these speeds no trouble was experienced in having the metal climb in the molds, and the taper does not exceed 3 or 4 degrees in a true bushing cast vertically.

For molds weighing up to 300 lb., we find that a 1 H.P. motor will provide sufficient power. From 300 lb. to 1,000 lb., we use a 5 H.P. motor. On one large machine, on which we install molds weighing up to 3,500 lb., we use a 20 H.P. motor. Most of the motor capacity is used for acceleration and breaking, so the frequency of the pouring cycle really determines the H.P. requirements. The figures given are safe on the 1 H.P. unit for a 10 min. interval; on the 5 H.P. unit for a 30 min. interval; and on the 20 H.P. unit for an hourly interval.

Consideration of Motor

There is considerable difference of opinion as to the advisability of using a single speed motor and the number of machines for the number of spindle speeds required, as contrasted with the variable speed units driven by either a variable speed motor or a hydraulic drive.

If the work to be produced is in relatively short runs, and there is a large variety of type and size of castings produced, the variable speed unit is obviously the most economical. However, if the production contemplated is high, for each item produced, the constant speed standard motor drive is far less expensive in both first cost and maintenance.

It seems to me that this is just a matter of arithmetic, if you know what work you have scheduled to produce. The chill effect in the casting of this gun bronze cam ring was found to be a function of the thermal capacity of the mold and, as it worked out later for other alloys and mixtures, a mold wall thickness of approximately two and one-half times the wall thickness of the casting to be produced will provide the proper chill effect without unduly shortening mold life.

Temperature Maintenance

Mold temperature can be controlled by the number of molds in circulation that pass by a pouring station. Mold temperatures should be maintained between 350 and 400° F., according to our experience, to get best results.

After most of the essentials, above enumerated, had been properly evaluated, a centrifugal casting machine was designed, consisting of a vertical spindle, driven by a standard general purpose constant speed motor through a V belt drive on step pulleys to give semi-permanent adjustment of speed (Fig. 2).

The 1 H.P. 300 lb. mold units were grouped, 8 on a merry-go-round, with a gravity conveyor arrangement to transport poured molds to mold cleaning stations, and to return cleaned molds for replacement on the spindles of the merry-go-round.

The bottom of the molds were

FIG. 2—EIGHT-UNIT CENTRIFUGAL MACHINE FOR BRONZE CASTING.

provided with a babbitted fit to centrally locate them on the spindle driving plates for facile removal and replacement of molds on spindles.

From 3 to 5 mold cleaning stations are required for each merry-go-round unit. These are located between the conveyor line coming from the merry-go-round and the conveyor line returning to the merry-go-round. Each cleaning station consists of a motor driven spindle very similar to the individual casting machine units that are merry-go-round mounted.

It has been found in practice that there is required a pool of from 30 to 40 molds in circulation on one merry-go-round unit, if economical operations are to be insured.

Furnace and pouring temperatures are taken and recorded on an indicating and recording potentiometer, wall mounted and wired to socket outlets at convenient locations. With this plug and socket arrangement, the tip immersion type thermocouples require only short flexible leads.

The indicating scale on the potentiometer can be read for a distance of 20 to 30 ft. The record roll on the potentiometer can be marked with the heat number so that the temperature of each heat becomes a matter of record. This arrangement has been found invaluable in the control of furnace and pouring temperatures.

It required approximately one year to develop and build a centrifugal casting production unit for this cam ring. It required another six months to stabilize the operation and develop the "know how" in a newly recruited operating crew. Soon, however, they became the op-

erations that we observed in development work that followed.

On the heels of this cam ring job came the large diesel engine main and connecting rod bearings. For this application, high lead bronze castings were suddenly demanded to replace steel back bearings made of tubing, which had "gone to war."

We were asked to produce a bearing blank that could be processed with the same tooling as was previously used for steel tubing, requiring that after the casting was semi-finished it, being split in half bearings, formed in a die to a smaller radius so that each half could be used.

Other Centrifugal Casting Projects

Projections also had to be formed by pressure dies at the parting line of the bearing to form "tangs" to prevent the rotation and end movement of the bearing in the housing. Sand cast lead bronze would not stand this treatment, but the same metal centrifugally cast in chill molds worked out satisfactorily.

The development of centrifugally cast procedure for high lead bronze paralleled that of the gun bronze cam ring, so the cam ring procedure became the operation that was observed for determining lead bronze casting procedure.

Duplicate equipment was used for the production of the high lead bronze ring, with necessary changes in procedure of metal melting, pouring temperature, mold wash spray, etc.

Our last centrifugal project was aluminum and manganese bronze bushings and gear blanks. Again, parallel procedures to those used on other metals were developed, varying temperatures, chill rates, melting and pouring procedure as required.

In the case of the aluminum and manganese bronze, we had to go back to the sand foundry and draw on the experience of the molders to eliminate any turbulance of metal during the pouring operations, especially of aluminum bronze. While the equipment developed and the procedure itself is nothing like anything in the sand foundry, it operates exactly on the same fundamental principles found there.

Conclusion

As can be surmised from the foregoing details, our activities have been confined largely to centrifugal chill casting to date. In our superficial work so far in centrifugal casting in sand, our efforts have not been particularly successful, and we are very doubtful if the high lead bronzes can ever be successfully centrifugally cast in sand.

Other foundries have been very successful in using carbon molds for true alloys and staple mixtures of bronze, another field in which we have done very little work. It is our opinion, however, that centrifugal chill cast bronze in metal molds will produce finer grain structure and improve physical characteristics over that cast in either sand or carbon molds centrifugally cast in bronzes.

In conclusion, it is felt that a better job has been done, if this gives a plan of attack on problems relating to centrifugal casting of bronze, rather than specific details that may or may not apply to some particular job.

Some Practical and Economic Aspects of Small Foundry Conveyorization

By Howard B. Nye*, Watertown, N. Y.

Abstract

When it is decided that foundry improvements should be made in order to promote greater efficiency and/or higher production, conveyors of one sort or another usually are among the first additions suggested. It is the purpose of this paper to discuss, with the aid of sketches, photographs, and actual production figures, some of the most frequently posed questions with regard to foundry mechanization.

Planning

1. When new equipment is contemplated in a small foundry, it is a good plan to make a large-scale drawing showing the arrangement of all existing equipment. The next move should be to study all of the various foundry operations, and from this data work up figures as to the cost per lb. or the cost per unit of the various operations; i.e., coremaking, molding, melting, cleaning, etc. When it is ascertained which of these operations is the most costly, or which operation is the limiting factor to more production, sufficient base data are available for an intelligent approach to the problem of additional mechanization.

2. Using the large-scale drawing of the existing set-up, various rearrangements may be experimented with by means of cut-outs, which may be shuffled from one location to the other over the drawing. Such preliminary work is carried out most successfully by some member of the existing staff, who is familiar with the day-to-day problems of the shop, and who enjoys the confidence and support of the foundry operating people.

3. At this point, it is wise to call in a service engineer from one or more of the companies which manufacture equipment of the sort which seems to be indicated; i.e., sand-handling equipment, monorail, roller conveyor, etc.

4. As a general rule, these engineers have had broad experience with foundry problems and the application of their equipment; also, if they represent one of the many first-line equipment manufacturers, they have a great deal of professional pride and usually make some very sound recommendations.

5. When the project has reached the stage where all concerned, and especially the operating department heads, are satisfied that the proposed changes will be a step in the right direction, some back checking is indicated;

---

*Asst. Foundry Supt., New York Air Brake Co.

Note: This paper was presented at a Plant and Plant Equipment Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 25, 1944.

first, to see if the proposed modernization will do all of the things it is planned to do, and second, to check the economics of the change over. A good method of checking the former is to visit some foundry or foundries which are operating similar equipment and comparing the data thus obtained with the estimates of the original plan.

6. In so far as the second point is concerned, it formerly was considered good practice to carry out a mechanization program only if the project would be self liquidating within a one-year period. However, present problems, such as labor shortages, taxation and war-jumbled production demands, often complicate the economics of conveyorization to the extent that it is difficult to make any fixed recommendations on this issue.

Sand Conveyors

7. The most common method of conveying sand is by means of belt conveyors and bucket elevators. Belt conveyors and bucket elevators are relatively not too expensive and offer a convenient means of conveying large quantities of sand at a low cost. However, they are not very flexible when and if it becomes necessary to replace or relocate existing molding or sand preparation equipment. Also, there are many exposed bearings which, in any sand handling job, result in a fairly high maintenance cost.

8. For the small foundry, a bucket arrangement (Fig. 1—left) is often much cheaper in first cost and more easily maintained than the bucket elevator and conveyor belt which it replaces. The unit is controlled by means of a five-button pendant attached to the hoist. The bucket is raised to traveling position by pushing button no. 1. It is moved forward and reversed by pushing button no. 2 or no. 3. When the bucket reaches the unloading point,

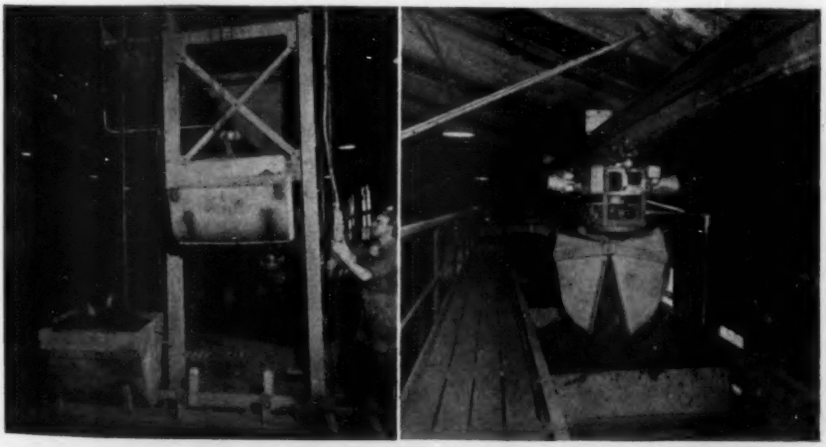


Fig. 1—Left—Sand-Handling Bucket Arrangement for Small Foundry. Right—Sand-Handling Bucket in Dumping Position.

button no. 4 is pressed, causing the bucket to raise slightly until the projecting arms forcibly contact the hoist ring (Fig. 1—right). This action causes the bucket to dump. Button no. 5 is pressed to lower the bucket to traveling height, whence it is again returned to the conveyor point where it is lowered to be refilled.

9. One person operates the complete sand conditioning system, which consists of a paddle aerator above a 25-ton storage tank which feeds a 4 cu. ft. muller (Fig. 2). With this system, an average of 4 tons of sand per hr. can be conditioned and distributed to as many as 10 molding stations

FIG. 2—VIEW OF 25-TON SAND STORAGE TANK AND 4-CU. FT. MULLER.

MOLD CONVEYORS

10. Molds usually are conveyed by means of a pallet conveyor, roller conveyor, or an overhead carrier.

Pallet Conveyors

11. Pallet conveyors usually are more expensive in first cost than other types of mold conveyors. However, where uniform production is obtainable and where alloy complications are not too great, they are a very efficient method of handling molds since material is always on the move. These units are more expensive to maintain than roller conveyors or overhead equipment.

Roller Conveyors

12. Roller conveyors are quite low in first cost and are very flexible, both in so far as present production demands are concerned and, also, when and if future changes in equipment location become necessary. Figure 3 shows how the flexibility of roller conveyors permits them to be utilized for storage

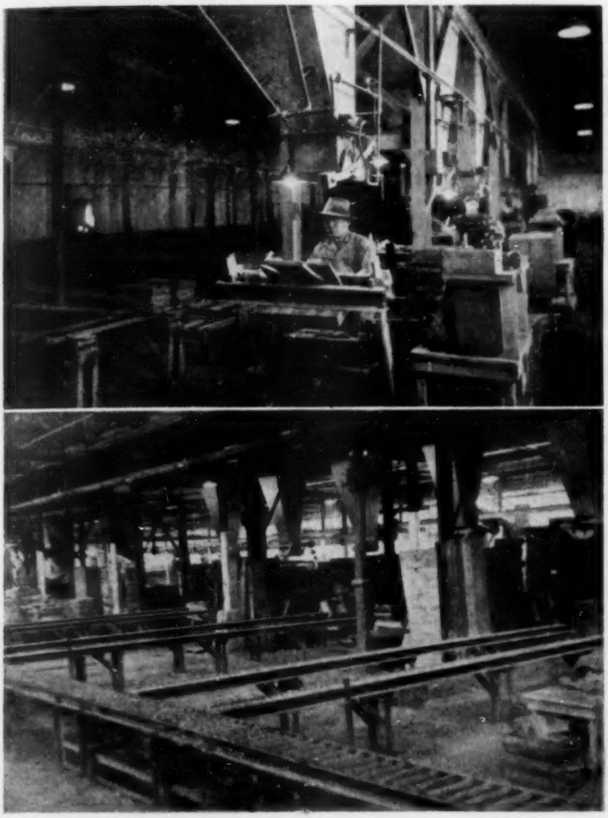


FIG. 3—VIEWS ILLUSTRATING HOW FLEXIBILITY OF ROLLER CONVEYORS PERMITS THEIR USE FOR STORAGE PURPOSES.

so that sufficient numbers of molds may be accumulated for the different heats of metal when several different alloys are being produced at one time.

Overhead Carriers

13. Mold carriers suspended from overhead monorails are very economical to install. They are flexible and also have the distinct advantage of leaving the floor clear of obstructions. They may be equipped for power travel or they may be hand-propelled. The hand-propelled method is a little the more flexible of the two in most small foundries; however, if the production is large and flow uncomplicated, power travel is more efficient. Figure 4 illustrates an application of the hand-propelled overhead mold conveyor.

SAND CONDITIONING

14. Strictly speaking, sand conditioning is not a conveyor problem; however, the two are so closely integrated that they should be discussed together.

15. There are many ways to condition sand. It may be screened and run through one of the many types of paddle mixers or aerators, or it may be mulled.

16. Sand may be screened at the shake-out point or at the elevator discharge point, where either a deck or a revolving screen may be used. The deck screen is very fast and is fairly economical to maintain; however, it does not break up lumps quite as well as the revolving screen.

17. After having had experience with sand conditioning systems of several different types, the author is convinced that molding sand should be mulled each time it is used. Mulling not only improves the quality of the sand, but it also saves money. Our records show that, when a sand-handling system equipped with a muller replaced hand cutting and riddling in our non-ferrous foundry, new sand additions were cut in half. There is no substitute for the kneading action of the muller.

18. Some of the muller manufacturers advertise and advise that the design of their equipment is such that aeration is unnecessary after the sand has been mulled in their machines. In the author's opinion, aeration improves any mulled molding sand. A muller is essentially a packer—a kneader. Aeration makes this thoroughly mixed sand light and permeable. Such sand is much less likely to stick to aluminum patterns than sand which is not aerated.

19. Sand and sand-conditioning problems are one of the major arguments in favor of a number of small, compact conveyor systems in a foundry where a variety of work is produced, rather than a single large unit. Considerable sand difficulty is apt to be encountered on the large system, which can be eliminated only by taking certain "fussy" jobs off the conveyor system and

FIG. 4—VIEW OF HAND-PROPELLED OVERHEAD MOLD CONVEYOR.

running them, at a greater cost, on the floor, where the proper sand can be prepared. If small systems are employed, much greater flexibility is obtainable, with consequently lower over-all cost and less scrap loss.

Proposed Layouts

20. Keeping in mind the factors of low first cost, relative efficiency and ultimate flexibility, two small foundry molding layouts have been prepared.

21. The first deals with the problems of a foundry having a long-run standard product which is poured from a single alloy. It is proposed to place four molding machines along a pallet conveyor (Fig. 5—top). These machines are to be supplied with sand which is transported from the sand-conditioning unit by means of an overhead track system. After the molds have been made, they are placed on the pallet conveyor upon which they travel through the pouring and cooling zones until they reach the shake-out, where they are dumped.

22. The sand is conveyed by belt conveyor and elevator to a screen which is mounted above a storage tank. The sand is fed from the bottom of the storage tank by means of a gate which is actuated by an ammeter on the sand mixer motor. When properly set, this device assures that uniform batches are supplied to the muller. After mixing, the sand is aerated and discharged into a bucket for distribution to the molder stations. Such a system will save its original cost within one year or less, if the demand is such that it is possible to run the unit at capacity for long periods.

23. When a foundry makes work of a jobbing nature, or work which is poured from several different alloys, a layout such as is shown in Fig. 5 (bottom) is suggested. The sand-conditioning unit is the same as was described for the production foundry. However, the molds, instead of being placed on a pallet conveyor, are placed on roller conveyors, where they are poured. When the metal has cooled, the molds are shaken out over a grate which covers a flight conveyor. This conveyor, supplemented by a belt and an elevator, returns the sand to the storage tank.

24. The flasks are returned to the molder on the parallel roller conveyors, which slope toward the molding machines. This type of conveyor system represents about the ultimate in economy, flexibility, and in over-all efficiency for the small foundry which may be called upon to make a wide variety of machine molded castings.

Conclusion

25. The mechanization of any foundry is a problem in engineering design, complicated by many practical considerations.

26. In order to solve any major engineering problem, certain basic data must first be established; hence, the recommended preliminary survey of all foundry functions.

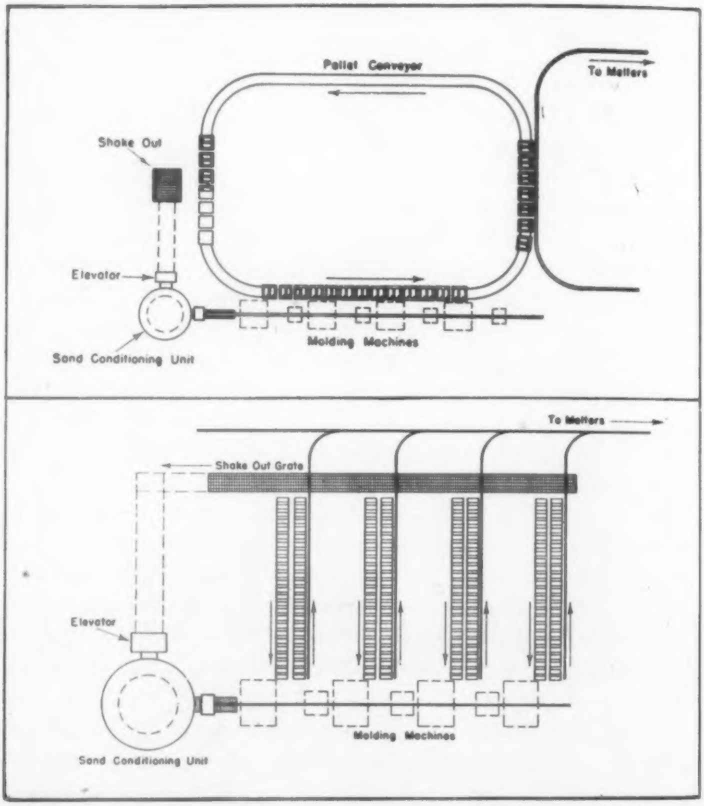


FIG. 5—TOP—PROPOSED PALLET CONVEYOR LAYOUT FOR A SMALL PRODUCTION FOUNDRY. BOTTOM—PROPOSED ROLLER CONVEYOR OR LAYOUT FOR A SMALL ALLOY OR JOBBING FOUNDRY.

27. A thorough knowledge of foundry practice, and, more important, an intimate knowledge of the every-day problems of the foundry in question, are essential elements that should go into the design of new foundry conveyor systems; hence, the suggestion that foundry operating people be consulted, assist with and approve the final design.

28. Conveyors can and do assist in the production picture. However, castings are produced by men and machines; no matter how well engineered, the machines alone can not deliver the goods. No foundry, no matter how well equipped, is any more efficient than its management.

Mold Surface Properties at Elevated Temperatures

By H. W. Dietert*, R. L. Doelman*, and R. W. Bennett*, Detroit, Mich.

Abstract

In this paper the authors have described tests performed to obtain information concerning the elevated temperature properties of mold surfaces, such as spalling, confined expansion, hot strength, and hot deformation. Data obtained from these tests are presented graphically.

Introduction

1. Our efforts in sand control are practically all directed towards forming a mold surface that is capable of withstanding the thermal shock, the static load and erosion of molten metal without contaminating the molten metal with gas, sand or other foreign material. It is true, however, that some of our efforts in sand control are expended in producing a sand that will work easily in the sense of rammability, flowability, liftability and toolability. The authors will define a number of the green sand properties under discussion to aid in clarifying statements made in this paper.

Definitions

Rammability

2. Rammability is to be differentiated from flowability. By rammability one refers to the ability of a molding material to ram to a firm mold surface that is capable of supporting a load. The degree of rammability may be measured with a mold hardness test made at varying distances from point of ramming application.

Flowability

3. The flowability property of a sand enables the sand grains to flow together when ramming energy is applied to form a uniform void space mold surface. The degree of flowability may be measured by a flowability indicator which expresses numerically the amount of void spaces present that are larger than inherent to the grain size of the sand.

4. A sand with low rammability may cause casting defects such as "swells,"

*Harry W. Dietert Co.

Note: This paper was presented at a Steel Foundry Sands Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 26, 1944.

due to soft spots on the mold surface, particularly at restricted portions of the mold. A sand with low flowability, coupled with insufficient ramming, may cause casting defects such as "metal penetration" which is due to large void spaces where the sand grains have not flowed together to touch each other.

Liftability

5. The liftability of a sand describes the ability of a sand to withstand the load and bending applied during the process of stripping the pattern or lifting of the mold.

6. *Green strength* will measure the ability of the sand to withstand the load applied.

7. *Green deformation* will measure the ability of the sand to withstand the bending stress.

8. *Toughness,* which is the product of green compression and green deformation, is our best single measure of liftability.

Toolability

9. Toolability of a sand is the ability of the mold surface to respond to hand tooling and patching.

SPALLING

10. The mold surface, whether it be green, dried or baked, is subjected to a very sudden rise in temperature during the pouring operation. This is generally spoken of as thermal shock. Many molding materials are not sufficiently stable thermally to withstand this quick temperature rise because of the stresses imposed by expansion or contraction of the molding material.

11. A molding material which does not crack, check or peel off on being subjected suddenly to a high temperature is said to be thermally stable. Such sands which have the combination at elevated temperatures of high confined expansion, probably the result of high flowability, and of a brittle nature which may be measured by low hot deformation, are not thermally stable.

12. At the present time, the best measure of thermal stability is the spalling test. The 1⅛-in. x 2-in. double-end rammed specimen is placed in the dilatometer furnace which is heated to the temperature of the molten metal in the mold. The molten metal temperaure in the mold is usually assumed to be 200° F. lower than pouring temperature.

13. For the spalling test, the first sand specimen is allowed to remain in the dilatometer furnace for a period of two minutes and is them removed for visual inspection. Such spalling, cracks or checks as may be present on the specimen surface are due to volume change from expansion.

14. A second specimen, which is allowed to remain in the dilatometer furnace for a period of 12 minutes, will show that such spalling, as well as

checks or cracks that will result from this prolonged heating, are due to contraction.

15. The photograph of the specimen in Fig. 1 furnishes a good record of the test.

16. Metal penetration defects are at times caused by the mold surface cracking, allowing molten metal to penetrate into the mold surface. This veining or cracking of mold surface easily may be seen on many sands that have undergone the spalling test described in the previous paragraph. A sand is made thermally stable by changing grain distribution and grain size and by binder additions.

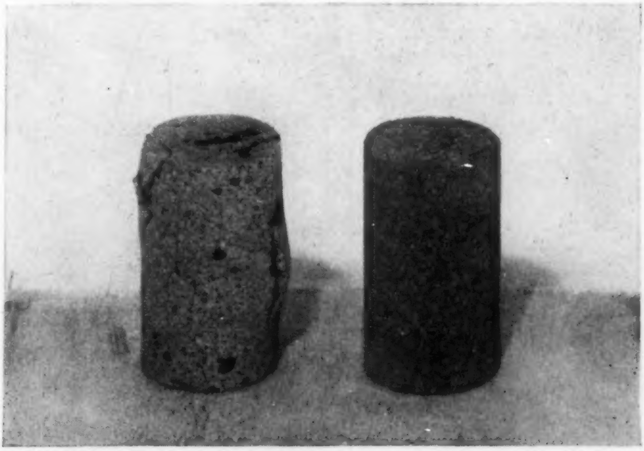


FIG. 1—SAND SPECIMEN ON LEFT SHOWS SPALLING WHILE THE ONE ON THE RIGHT IS FREE OF SPALLING.

CONFINED EXPANSION

17. Considerable data has been presented on the free expansion of molding sand. In the free expansion test the sand specimen is free to expand in circumference as well as in length. The free expansion test is greatly influenced by hot strength—that is, the ability of the sand to support itself. Due to the very wide variation of hot strength, it is only natural that free expansion data is of little practical value without much correlation of other factors.

18. The confined expansion test was developed to facilitate the practical application of expansion test data. In the confined expansion test the 1⅛-in. x 2-in. test specimen is rammed in a quartz tube 1⅛-in. I.D. and 3-in. in length. A special specimen tube, shown in Fig. 2, is used to hold the quartz tube while the specimen is rammed with the usual 1⅛-in. double-end sand rammer.

19. Refractory discs are inserted in each end of the rammed specimen in the quartz tube to give a firm seat to the ends of the sand specimen. The quartz tube containing the molding sand or core specimen with the two discs in place

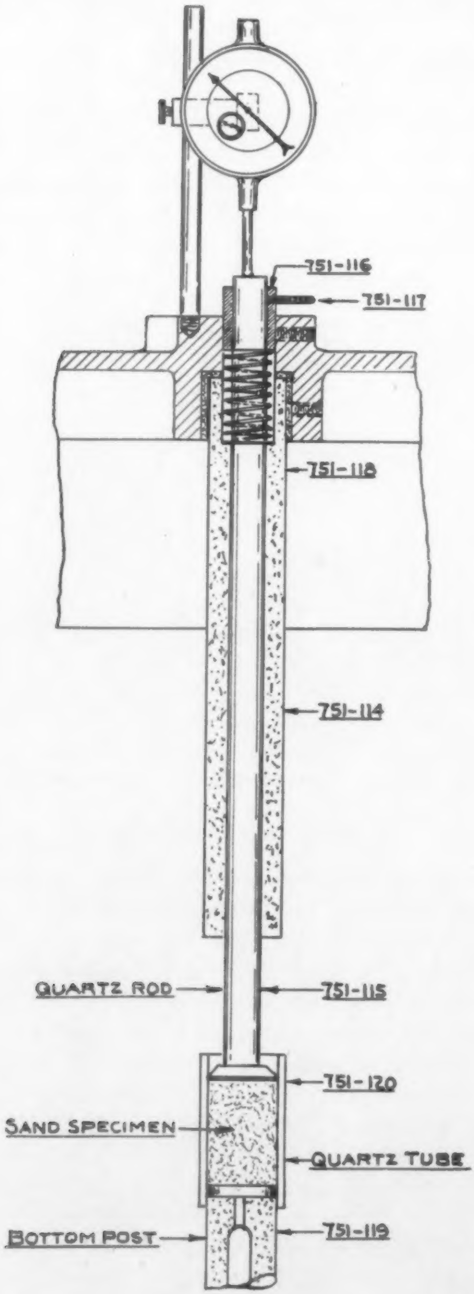


FIG. 2—METHOD OF RAMMING SAND SPECIMEN AND MOUNTING FOR CONFINED EXPANSION TEST.

is then set on top of the bottom rigid post of the dilatometer. A quartz rod with a small bore hole makes contact with the top refractory disc resting on the sand specimen. This rod transfers the expansion or contraction of the specimen to a dial indicator. A blank calibration test, without sand specimen, is made to determine the expansion of the quartz rod and support. Test data is corrected for the blank calibration reading. The specimen is heated by a dilatometer furnace to metal pouring temperature.

20. Since the specimen is confined within the quartz tube during the test, the volumetric growth or shrinkage is measured under conditions simulating those found within a mold or core. By measuring confined expansion at temperatures corresponding to those of cross sectional zones found in a mold or core, one is able to determine the volume change of a sand in a mold. However, it is felt that only the outer layer of a mold causes surface defects originating from expansion or contraction. One may draw some helpful conclusions from confined expansion tests made at molten metal temperatures. As a rule, molding material with the lowest confined expansion is favored. A low hot shrinkage is indicative of high refractoriness.

Comparison Between Confined and Free Expansion

21. Since our past concepts of the growth of molding materials were based on free expansion, a few comparisons between free expansion and confined expansion tests are in order.

22. Of the natural sands, Albany sand has a very low growth. Figure 3 shows both the free and confined expansion curves for a No. 1½ Albany sand. For all practical purposes, this sand does not show much difference between free and confined expansion except that, in the case of free expansion, expansion at the beginning of the test is fast. On prolonged heating, the free expansion test curve shows a greater contraction or hot shrinkage.

23. A further study of this growth phenomena may be made by comparing the dilation curves in Fig. 4. The *A* dilation curves show the volume change of a No. 17 washed and dried Ottawa sand bonded with 4 per cent Western Bentonite. The *B* dilation curves show the volume change of the same sand mix, except that 5 per cent sea coal was added. This comparison exemplifies the general rule that expansion is reduced by the addition of combustible materials to foundry sands.

24. The maximum confined expansion of the A mix without sea coal is 0.037-in. as compared to 0.018-in. for B mix with sea coal, which represents a 50 per cent reduction in growth.

25. A comparison of the free expansion curves does not show as great a reduction.

26. A comparison of hot shrinkage, which is defined as the difference between maximum expansion and maximum contraction at twelve minute soaking period, show that sea coal slightly increases confined hot shrinkage.

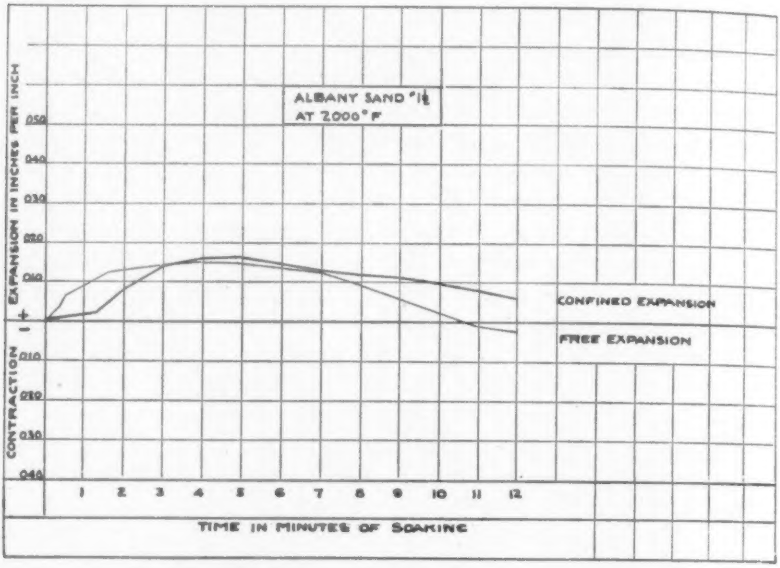


FIG. 3—CONFINED EXPANSION AND FREE EXPANSION OF AN ALBANY SAND.

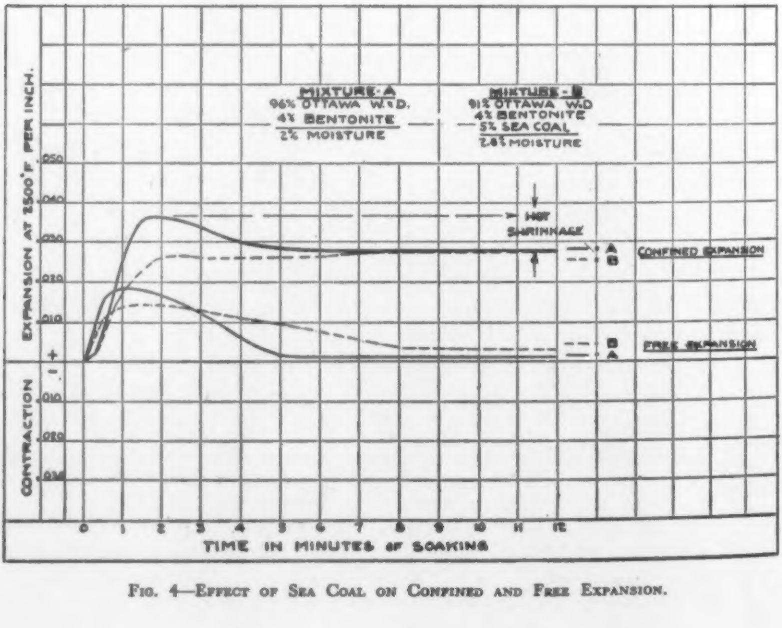


FIG. 4—EFFECT OF SEA COAL ON CONFINED AND FREE EXPANSION.

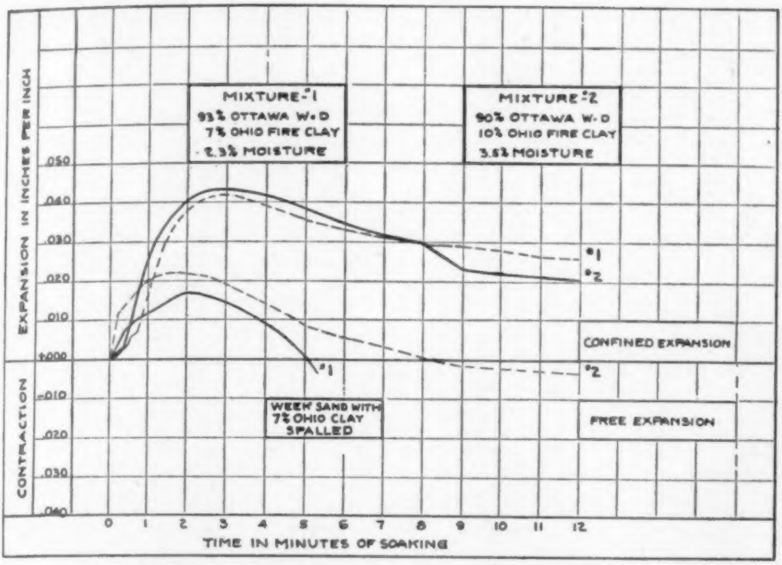


FIG. 5—CONFINED AND FREE EXPANSION OF BONDED OHIO FIRE CLAY SAND.

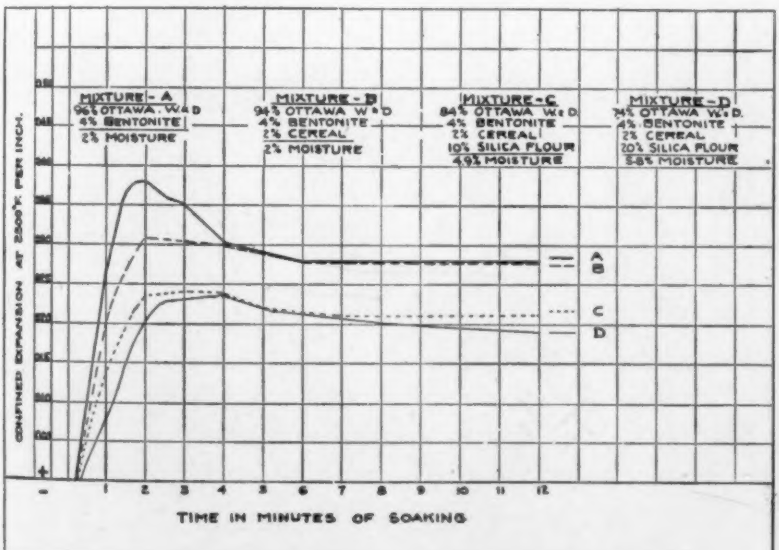


FIG. 6—CONFINED EXPANSION FOR GREEN SANDS.

27. Free expansion does not enable one to measure correctly the expansion or hot shrinkage of molding materials. This is well demonstrated in dilation curves Nos. 1 and 2 in Fig. 5.

28. The dilation curve No. 1, Fig. 5, illustrates the growth and hot shrinkage of mix No. 1, consisting of No. 17 washed and dried Ottawa sand bonded with 7 per cent Ohio clay. Dilation curves No. 2 are for mix No. 2, consisting of the same sand but with 10 per cent Ohio clay bond. Note that the free expansion dilation curves show less than half of the actual growth.

29. It is interesting to note that the No. 1 mix with 7 per cent bond has a hot shrinkage of 0.018-in., while No. 2 mix with 10 per cent bond shows a hot shrinkage of 0.022-in. Bonding material may be considered in the nature of a flux reducing the refractoriness of foundry sands.

30. To study the effect of cereal binder and silica flour additions to green sands, the confined expansion curves shown in Fig. 6 are of value.

31. Mix A consists of No. 17 washed and dried Ottawa sand bonded with 4 per cent Western Bentonite. The mix shows a maximum confined expansion of 0.037-in. Mix B is identical to mix A except that 2 per cent cereal binder was added. The maximum confined expansion was reduced from 0.037-in. to 0.031-in. No change in hot shrinkage was shown.

32. The amount of the particular type of cereal binder used was sufficient to reduce the flowability of the sand, which undoubtedly accounts for a large portion of the reduction in confined expansion.

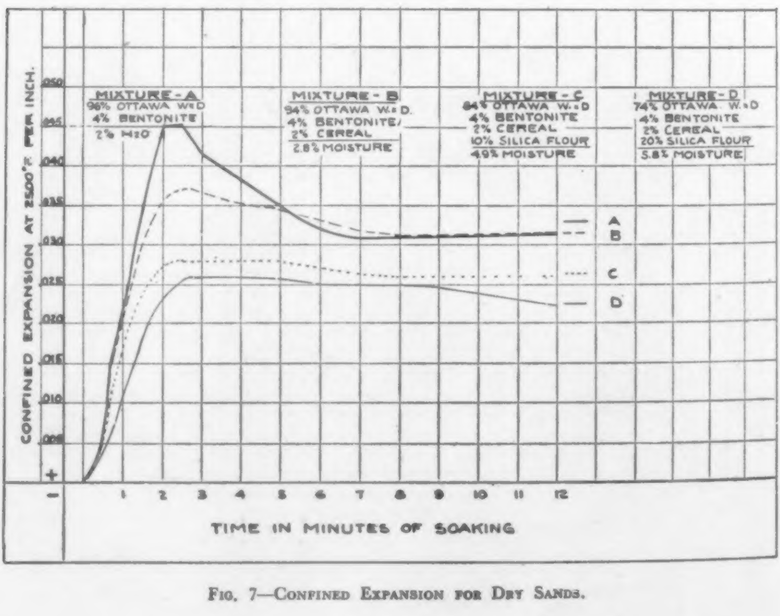


FIG. 7—CONFINED EXPANSION FOR DRY SANDS.

33. In previous work with free expansion, it was shown that the addition of silica flour to a sand increased the free expansion. It is known that free expansion test data was influenced to a great extent by the increase of hot strength.

34. Mixes C and D in Fig. 6 contained 10 per cent and 20 per cent additions of silica flour. It may be noted that the confined expansion was reduced to a value of less than .025-in.

35. Using confined expansion as the criterion, it may be stated that silica flour reduces the confined expansion or growth of a sand.

36. The hot shrinkage of a sand is reduced by the addition of silica flour.

37. Many large castings are made in dried molds so that it is of technical interest to know the confined expansion of dry sand mixtures. In Fig. 7 are shown confined expansion curves for dried specimens of the sand mixes A, B, C and D. The same relation holds for the dry sands of Fig. 7 as for the green sands of Fig. 6. The only apparent difference is that the dry sands show higher expansions. Using mix C as a typical steel foundry sand (except that the percentage of cereal binder is quite high, purposely made so to show more clearly the effect of cereal binder) the confined expansion curves for the dried and green sands are shown in Fig. 8. The heat penetration into a green sand is slower than into a dried sand. This causes the dried sand to have a slightly faster rate of expansion.

38. The green sand also benefits some from the cushioning effect of the soft green sand, as compared to the rigid dried sand.

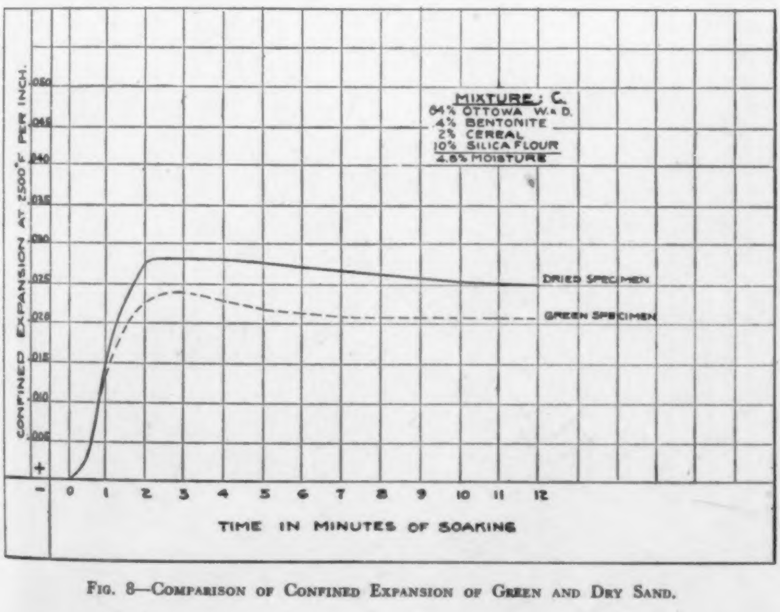


FIG. 8—COMPARISON OF CONFINED EXPANSION OF GREEN AND DRY SAND.

39. In all sand molds, a limited amount of cushioning effect is desirable. An efficient way to obtain this cushioning effect is to have a multiplicity of minute void spaces present or available between the sand grains to accommodate grain growth or rearrangement of grains without breaking the mold surface or cracking the casting.

40. Whenever the flowability of a sand is reduced, the void spaces between the sand grains increase. Thus one can expect a reduced confined expansion for a given sand moisture whenever the flowability, as measured with the flowability indicator, is reduced. The correlation between flowability and confined expansion of green sand mixes A, B, C and D of Fig. 6, as shown in Fig. 9, graphically illustrates that a reduction of flowability reduces expansion of the mold surface.

41. In Figs. 6 and 7 it was shown that cereal binder, when added to a molding sand, reduced confined expansion. It should not be considered that this reduction in confined expansion would hold regardless of other conditions. For example, one can actually cause cereal binder to increase confined expansion in a core mixture if one allows baked strength to increase by not reducing the other binders. In such a case, a marked increase in baked strength would increase the expansion, thus reducing or cancelling the expansion reduction power of cereal binder. This is illustrated in Fig. 10. In mixture No. 3, consisting of 60 parts of No. 17 washed and dried Ottawa sand and 1 part linseed oil, a baked tensile strength of 225 lb. was obtained. This mix showed a confined expansion of 0.030-in. This same mix with an addition of 1 per cent

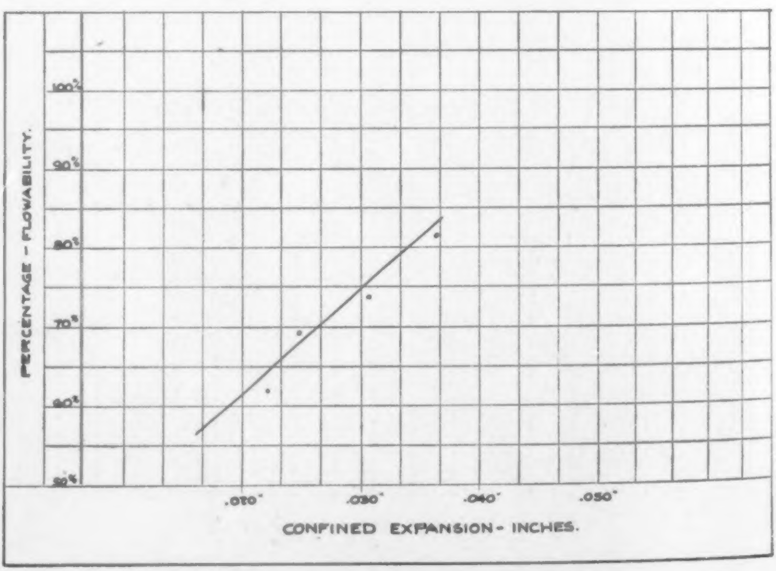


FIG. 9—RELATION BETWEEN CONFINED EXPANSION AND FLOWABILITY.

cereal, designated as No. 4, resulted in a tensile strength of 342 lb. and a confined expansion of 0.035-in. The increase in tensile strength increased the expansion and also caused mix 4 to collapse at a slower rate than mix 3.

RATE OF HOT STRENGTH DEVELOPMENT

42. Whether the mold surface be green or dry, the rate at which the green or dry strength of the sand develops into hot strength on the mold surface is a factor that may help foundrymen to more fully understand the many molding problems. Hot strength of a number of representative foundry sand mixtures was determined at various intervals of time of soaking at elevated temperatures. Many have correctly surmised that molding sand is quick to respond to thermal shock of elevated temperatures.

HOT STRENGTH OF GREEN SAND VERSUS TIME OF SOAKING

43. The rate at which a green sand develops or builds up hot strength when subjected to a molten metal temperature, for example, 2500° F., is well illustrated in Fig. 11.

44. Using the green sand mix D containing No. 17 washed and dried Ottawa sand and 4 per cent western bentonite as the base sand, one may find by referring to Fig. 11, curve D, that this green sand which possessed 6.5 lb. green compression strength developed a hot strength of 28 lb. in one minute of soaking in a temperature of 2500° F. On further soaking at this tempera-

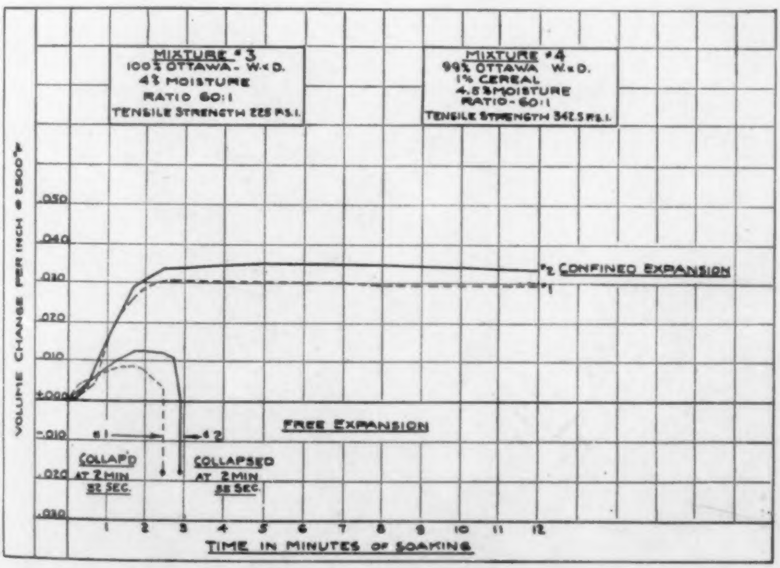


FIG. 10—CONFINED AND FREE EXPANSION OF OIL SAND CORES.

ture, the hot strength decreased to an average of 1.5 lb. The peak strength at one minute is undoubtedly due to rapid drying of the sand, producing a dry strength. On soaking beyond one minute, this dry strength is destroyed. Nevertheless, the quick development of mold strength from 6.8 to 28 lb. certainly explains why green sand molds are capable of making fairly large castings.

45. An addition that one may make to a sand mixture is cereal binder. Adding a high value of 2 per cent cereal binder to mix D, it may be noted from curve C in Fig. 11 that cereal binder does not materially change the hot strength of this sand, except that the time of the first hot strengh peak development is decreased from 60 seconds to 30 seconds. This may be accounted for by the quick dry strength development of cereal binders, probably a worthwhile factor in green sand molds.

46. All of us realize that silica flour is a potent addition and that its addition to mix C should have a marked effect on the hot strength development. This is borne out by the hot strength curves A and B of Fig. 11, containing respectively 20 and 10 per cent silica flour.

47. Mix B containing 10 per cent silica flour develops a hot strength of 88 lb. in 30 seconds, while mix A with 20 per cent silica flour develops 80 lb. in the same period. The heat travels faster in the more open 10 per cent silica flour sand.

48. On soaking for a minute, the 20 per cent silica flour mix A develops the maximum hot strength of 91 lb., while that of mix B falls to 80 lb. These peak hot strengths are probably due to the development of dry strength. Figure 11 reveals that this dry or hot strength is reduced on soaking from 1½ to 3½

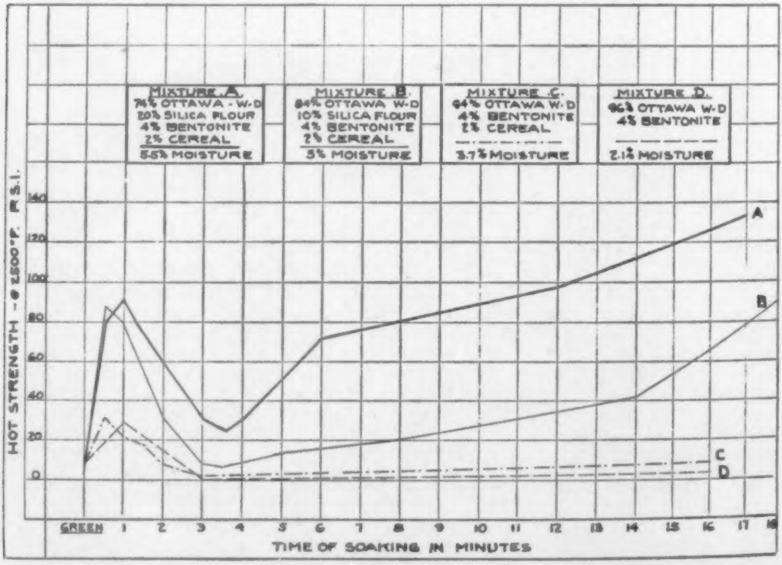


FIG. 11—HOT STRENGTH OF GREEN SAND AT 2500° F. AS AFFECTED BY SOAKING TIME.

minutes for mixes A, B, and C. Continuing the soaking time from 3½ minutes to longer periods of several hours produces a hot strength of increasing value. This is the true hot strength of a sand. However, the quick hot strength produced at ½ to 1½ minutes of soaking really determines the quality of the casting surface and undoubtedly is the important hot strength.

Hot Strength of Dry Sand Versus Time of Soaking

49. In the case of a dry sand mold, one starts with a dry strength that is high compared to the other strength values. It is thus natural to assume that the strength of a dry sand mold surface decreases upon being subjected to the temperature of molten metal.

50. The strength curves in Fig. 12 exemplify the development of hot strength of a dry sand bonded with bentonite, cereal binder and silica flour. The mix D contains No. 17 washed and dried Ottawa sand and 4 per cent western bentonite. When dried, this mix starts at a dry strength of 50 lb. and with 30 seconds of heating in an atmosphere of 2500° F., this strength is reduced to 12 lb., an appreciable reduction. The hot strength decreases up to a period of 4½ minutes soaking after which a slight increase in hot strength is noticeable.

51. With the addition of 2 per cent cereal binder, the original dry strength is increased from 50 to 70 lb. The development of hot strength of this sand is similar to that of sand without the cereal except that a very small increase in hot strength is noticeable.

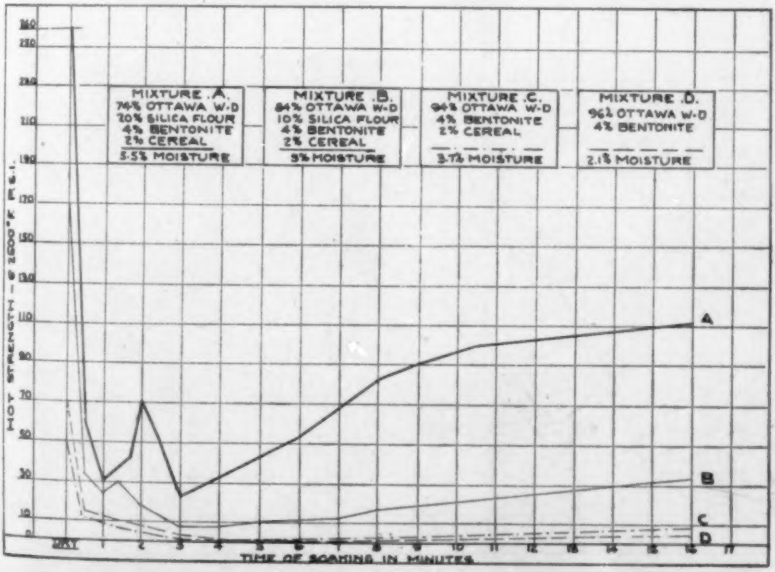


Fig. 12—Hot Strength of Dry Sand at 2500° F. as Affected by Soaking Time.

52. When 10 per cent silica flour is added, the dry strength is increased to 120 lb. (See curve B, Fig. 12.) Upon being placed in a 2500° F. atmosphere, the dry strength falls off suddenly, reaching 35 lb. in 30 seconds. This drop continues until a minimum of 8 lb. is reached at 4 to 5 minutes of soaking. The sand mixtures without silica flour reach a low of 0.5 lb. This is probably the point at which the mold surface erodes and causes dirt inclusions.

53. The 20 per cent silica flour sand mix B, on heating from 5 to 16 minutes, produces an increase in hot strength up to 33 lb.

54. The addition of 20 per cent silica flour to sand mix A produces a dry strength of 260 lb. which is suddenly reduced to a value of 30 lb. within one minute of heating at 2500° F. The dry strength of a dried mold surface is thus destroyed very rapidly within a period of one minute upon being subjected to the heat of the molten metal. Addition of silica flour increases the value of the minimum hot strength reached.

55. A point of particular interest is the secondary peak hot strength that is produced after this minimum strength is reached. Fig. 12 shows a secondary peak at 1¼ minutes for the 10 per cent silica flour sand (mix B), while a very pronounced peak of 70 lb. is developed at 2 minutes for the 20 per cent silica flour sand (mix A).

56. The authors wish to describe this secondary hot strength peak development as a "pyro strength" development. This pyro strength or secondary hot strength peak is developed whenever silica flour or fine siliceous material, such as found in some sands or bonds, is present in an appreciable amount.

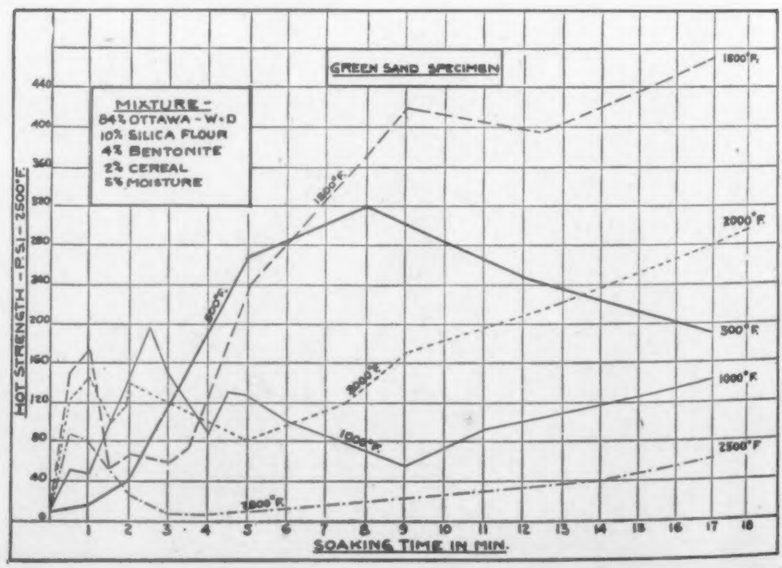


FIG. 13—HOT STRENGTH OF GREEN SAND VS. SOAKING PERIOD AT 500, 1,000, 1500, 2000, AND 2500° F.

57. The 20 per cent silica flour sand mix A, Fig. 12, develops a maximum hot strength of 112 lb. when heated for a period of 16 minutes at 2500° F. Silica flour additions to molding sands or cores furnish a means of obtaining maximum increase in hot strength.

HOT STRENGTH DEVELOPMENT FOR TEMPERATURES FROM 500 TO 2500° F.

58. It is appreciated that only a very thin layer of the mold is heated to temperatures as high as 2500° F. by molten ferrous metal. In molds and cores into which molten ferrous metal is poured, there are sections of the mold or core that are heated to temperatures which one may designate as 2500, 2000, 1500, 1000 and 500° F. zones. A 212° F. zone is also present, but it lies outside the scope of this paper.

59. In each of the temperature zones indicated in the previous paragraph, the sand passes from a green or dry strength into a hot strength phase.

60. The hot strength curves shown in Fig. 13 illustrate the development of hot strength at various temperatures from 500 to 2500° F. and various soaking times for a green sand mixture consisting of:

84 per cent No. 17 Ottawa Sand, Washed and Dried
10 per cent Silica Flour
4 per cent Western Bentonite
2 per cent Cereal
5 per cent Moisture

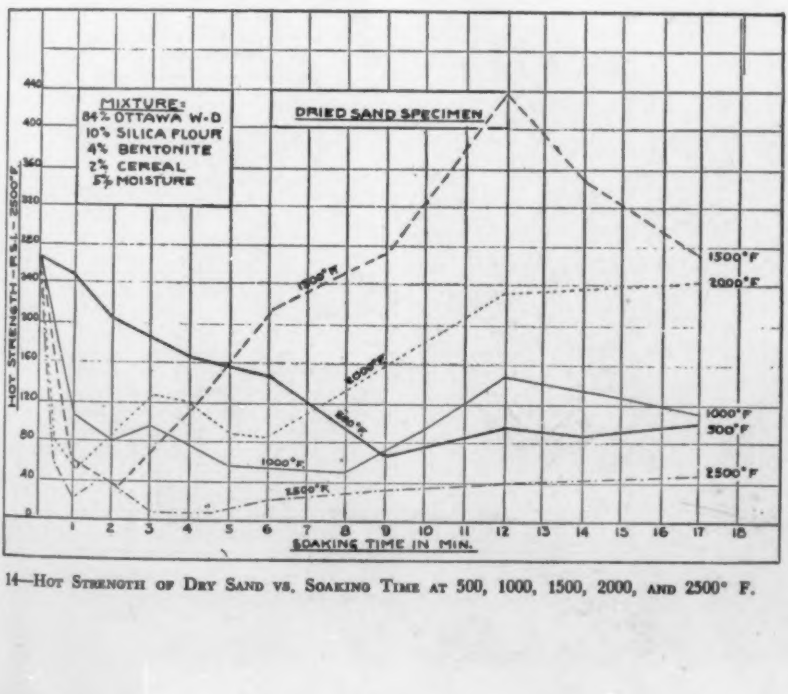


FIG. 14—HOT STRENGTH OF DRY SAND VS. SOAKING TIME AT 500, 1000, 1500, 2000, AND 2500° F.

61. Referring to Fig. 13, one is impressed by the high hot strength of sand at 1500° F., the slow development of a hot strength at 500° F., and by the relatively low hot strength at 2500° F.

62. Using the first peak of hot strength as an index point, it is interesting to note that the order of maximum strength is 500, 1000, 1500, 2000 and 2500° F., a drop in the first peak hot strength with an increase of temperature.

63. The behavior of a dry sand under conditions described in preceding paragraphs shows a much different picture for the same sand mix as shown in Fig. 14. For example, at all temperatures, namely, 500, 1000, 1500, 2000 and 2500° F., a rapid decrease in strength is experienced upon immersion in a furnace heated to the stated temperatures.

64. Temperatures 1500 and 2000° F. are the only temperatures that are capable of developing an appreciable rise in hot strength upon prolonged heating.

65. It may be stated generally that for short soaking periods hot strength

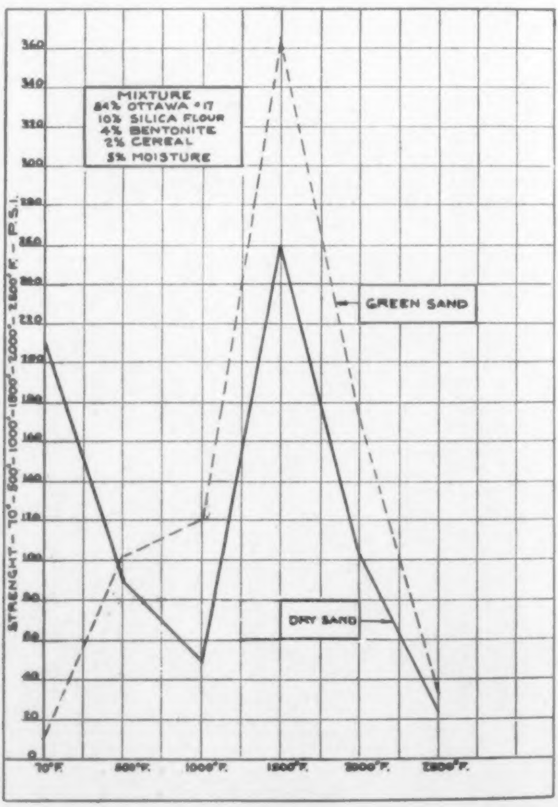


FIG. 15—COMPARISON OF HOT STRENGTH OF GREEN AND DRY SAND AT 12 MINUTES SOAKING TIME.

of bentonite bonded sand with a limited silica flour content is of the decreasing order for dry sands, while of an increasing order for green sands.

66. Under long soaking periods such as 12 minutes, the difference between the hot strength of a green sand and dry western bentonite bonded sand is not very large, as is well illustrated in Fig. 15 when the temperature is above 1000° F.

67. The hot strength development curve for a sand bonded with an Ohio fire clay follows a trend showing much kinship to that of a western bentonite bonded sand. The hot strength at 2500° F. of a typical steel facing sand in the green and dry condition presents a picture very similar to a bentonite bonded sand containing silica flour (Fig. 16). Compare the curves in Fig. 16 with the B curves in Figs. 11 and 12. Fire clays contain a portion of fine siliceous material that is similar to silica flour so that the first peak hot strength (pyro strength) should show prominently in the case of fire clay bonded sands. It is very probable that this explains the success experienced with clay bonded sands for heavy castings since silica flour is added automatically.

CONCLUSIONS

68. The following conclusions may be drawn concerning mold surface properties at elevated temperatures:

1. Spalling tests furnish a practical means of determining the thermal stability of foundry mixtures.

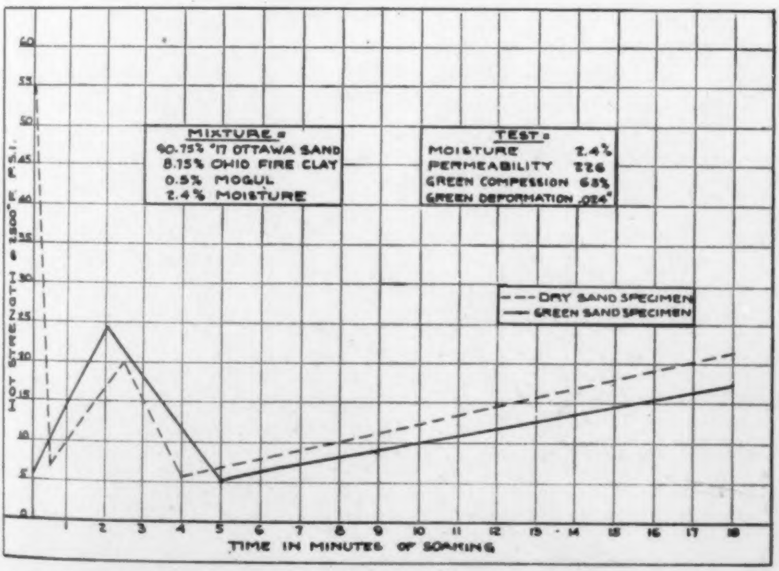


FIG. 16—DEVELOPMENT OF HOT STRENGTH OF CLAY BONDED SAND.

2. The confined expansion test is a better test than the free expansion test.
3. The confined expansion test furnishes data that is necessary as basic knowledge. It cannot be applied as a hard and fast rule to practical problems.
4. For a quick picturization of confined expansion and its correlation with sand additives, refer to Fig. 17.
5. Materials such as silica flour, sea coal, core oil and cereal binder reduce confined expansion.
6. Additions of bentonite clay and other binders added to silica sands reduce the confined expansion of the base sand; for example, No. 17 washed and dried Ottawa sand produced a confined expansion of 0.475-in. which is higher than that of mixtures produced from this sand. (Refer to Fig. 17.)
7. Lowering the flowability reduces confined expansion.
8. When the mold surface of green sand is subjected to heat of

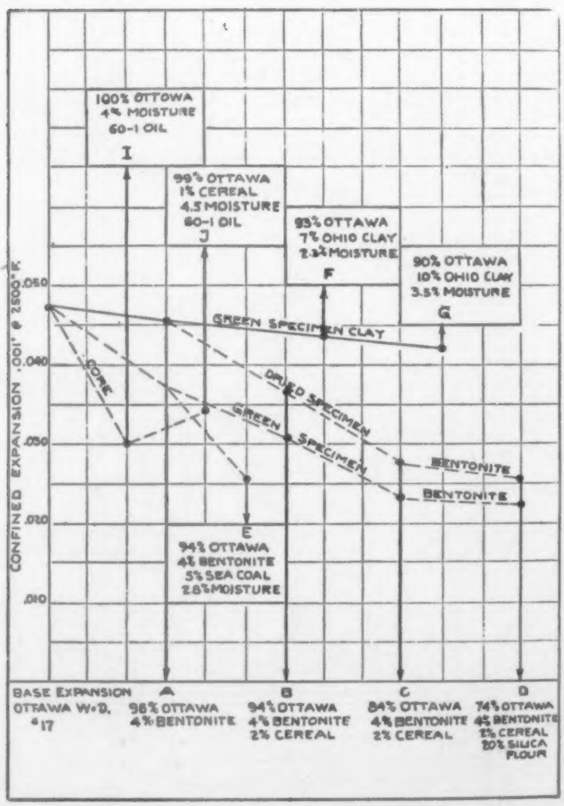


FIG. 17—CONFINED EXPANSION OF FOUNDRY SAND MIXTURES.

molten metal, a hot strength some 10 times greater than the green strength is produced within the first minute.

9. The addition of silica flour to green sands materially increases this quick hot strength.
10. When the mold surface of a dry sand is subjected to the heat of molten metal, the dry strength is quickly reduced to a hot strength much lower in value than the dry strength. This all takes place in the first minute of pouring the mold. On continued heating, the dry sand develops an increasing hot strength.

DISCUSSION

Presiding: D. L. PARKER, General Electric Co., Revere, Mass.

E. PRAGOFF[1]: Is the curve of flowability determined by modifying the properties of the synthetic bonded sand (Fig. 9)?

MR. DIETERT: In this work, we use a synthetic sand and different percentages of bentonite. For example, that particular curve (Fig. 9) covered the bentonite-bonded sand. We used as high as 2 per cent cereal binder, which made a very stiff mixture. More points on the curve were obtained by adding 10 per cent silica flour and 20 per cent silica flour. The stiffer the sand for an equal amount of ramming, the greater the distance between the sand grains, which corresponds to a low flowability. This would be synonymous to ramming a sand soft. Thus, if we have a sand rammed, let us say, apparently soft, we have more void space between each and every sand grain, allowing each sand grain to grow without touching another sand grain. So by increasing the void spaces between the sand grains, we do reduce the confined expansion. We are not advocating, necessarily, low flowability sand, but we do feel that it is a basic principle which must be remembered.

MR. PRAGOFF: Then, actually, you have four different sands on one curve rather than one variable. Would it not be rather difficult to get flowability with one variable?

MR. DIETERT: Yes, it would be quite difficult unless we make that one variable moisture. Then, unfortunately, at temperatures where the clay substance has the greatest degree of stiffness, we would have the lowest flowability. Possibly that is one reason we have the lightest sand when we have sand at temper. The clay is, let us say, swelled to the maximum extent. Molding sands that are high in moisture have an exceedingly low degree of flowability. For that reason, most of us, when we run core sand mixtures in the core blower, run the sand with a low moisture content to obtain the maximum flowability.

MR. PRAGOFF: Are any of the foundries using confined expansion tests today?

MR. DIETERT: I do not know of any foundry that is using the confined expansion test. In England, Mr. Buchanan ran a series of tests several years ago where he loaded the sand specimen with different degrees of load and measured expansion under varying load. In our new expansion test, we are trying to measure expansion volumetrically. We believe it is actually superior to the old free expansion test.

H. W. MEYER[2]: How do you account for the reduced expansion value obtained with increasing amounts of silica flour?

MR. DIETERT: In the case of free expansion, the silica flour gave a very firm sand

---

[1] Hercules Powder Co., Wilmington, Del.
[2] General Steel Castings Corp., Granite City, Ill.

specimen, which stood up under heat, and, therefore, we obtained a high free expansion value. In those days, we stated that increasing the silica flour content increased the expansion of the sand. In the case of confined expansion, when we add silica flour, we get a reduced expansion value. I have no explanation for the reduction in confined expansion when silica flour is added.

DR. H. RIES[3]: Do these confined expansion figures agree with the expansion tests that you have been making with the quartz rod, and the specimen not confined in a tube?

MR. DIETERT: The confined expansion tests are higher. There is a certain amount of sag in the sand specimen in the case of the free expansion test. In the case of the confined expansion test, we have a slight increase in the diameter of these quartz tubes. We did not make correction for this slight error. But the confined expansion values are much higher. The confined expansion tests are easily duplicated. There are some sands which fuse very badly at 2500° F., the sand sticks to the sides of the quartz tube, and we get erratic contraction figures at the end of the test.

DR. RIES: That might tend to reduce the expansion.

MR. DIETERT: In the case of the silica flour, the strength of the expansion is so great that it will break the quartz tube. In the case of using some low temperature, such as 1600° F. for the bentonite-bonded sands, where the sand grips the sides of the tube, the tube is often broken. The expansion force is very great; either the tube breaks or the sand expands lengthwise; but in the case of contraction, the force is so small that it does not always contract to the same point.

MEMBER: Have you ever run any tests on wood flour?

MR. DIETERT: We have not. I do not know just what we would get.

D. WILLIAMS[4]: Is there any relationship between expansion and volume change? In other words, if you have a linear expansion figure, how much does that mean in volume change?

MR. DIETERT: We have not made this correlation.

MR. WILLIAMS: If we have an expansion of 0.04 in. per in., that is approximately a 12 per cent volume change, and if we measure from a linear expansion standpoint, are we measuring the linear expansion or a combination of effects?

MR. DIETERT: In our tests we actually measured volumetric expansion. The sand mixtures we used for these confined expansion tests had high expansion values. We have used mixtures that had exceedingly high expansion to show clearly the effect of certain changes.

C. G. LUTTS[5]: Do you find that different sands show different expansion characteristics, dependent on the source? Also, does the expansion in the sand become permanent, once the sand has been heated?

MR. DIETERT: Sands from different sources do have different expansion, first because they have different impurities. If there is an impurity in the sand which will contract, or start to contract, at a relatively low temperature, around 2000° F., it naturally would affect the expansion at 2500° F. Impurities probably account for more change in expansion, according to the origin of the sand, than does the shape of the sand grain. The shape of the sand grains does affect expansion, because it affects the flowability. But one other thing that markedly affects expansion of sand grains is their size and their grain distribution. Thus, sands from different pits would have different expansions. The naturally-bonded sands, as a rule, have a much lower expansion than do synthetic sands.

[3] Cornell University, Ithaca, N. Y.
[4] Cornell University, Ithaca, N. Y.
[5] U. S. Navy Yard, Boston, Mass.

Malleable Mixture Calculation and Melting Control

By M. E. McKinney*, Hamilton, Ont.

Abstract

The choice and proportions of raw materials in malleable charges and the control of melting are often subject to rule of thumb methods. Fairly satisfactory results are obtained in this way when those directly in contact are of long experience and endowed with a certain intuition. Even this fails too often when the supplies of raw materials become irregular in some of their characteristics. Wartime shortage of experienced help and of regular supplies of staple raw materials makes it more than usually difficult to operate by rule of thumb methods. The author has dealt with this problem in two of its phases. First, the choice and proportion of materials in malleable mixtures has been reduced to a purely mathematical formula based on the law of averages so that the making up of the charge sheet may be placed in the hands of any one with normal arithmetical proficiency and without any knowledge of metallurgy or of melting. Second, the operation of a powdered coal fired air furnace is controlled by a continuous indicator of exit-gas analysis, coupled with a sensitive gauge showing draft or pressure inside the furnace. The application of the above principles over a year's time has resulted in a definite reduction in the quantity of furnace additions.

Introduction

1. In melting iron for malleable castings the same problem presents itself as in most other manufacturing operations, that of constant duplication of results. In this particular case the primary object is twofold, that of producing a white iron which (1) after annealing, will produce castings of the required physical properties, and (2) will have sufficient fluidity to pour molds with a minimum of misruns. Secondary considerations are fuel, refractory and labor costs.

2. With exceptions so rare as to be negligible, white iron of the proper analysis will produce good malleable castings when subjected to the proper annealing cycle. By white iron is meant iron free from graphite precipitation

*Chief Metallurgist, Hamilton Works, International Harvester Co.

Note: This paper was presented at a Malleable Iron Founding Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 26, 1944.

in all sections; by proper analysis is meant all desired elements included; and by proper annealing cycle is meant correct times, temperatures and atmospheres at the exact spot in the furnace where the casting is annealed. The occasional apparent exception is usually a simple lack of accurate information on one of the above points.

3. This then narrows down the requirements of malleable melting to producing hot iron of the proper chemical composition. As long as the raw materials entering the charge are carefully inspected, the only elements that require attention during the melting process are carbon, silicon and, on rare occasions, manganese.

4. With the desired analysis of the finished castings fixed and the changes in melting properly predicted, making up a charge sheet becomes nothing more than a simple mathematical calculation. A necessary adjunct to this calculation is accurate chemical analysis of the materials in the charge and of the resulting white iron. With these figures at hand it is possible to arrive at any predetermined chemical composition within limits set by the variations inherent to any particular melting installation.

PIG IRON AND SCRAP

Grades

5. Two grades of pig iron are all that are necessary, one high-silicon grade and one low-silicon grade. The other elements in the pig iron should be as nearly identical as possible. In addition to the pig iron, a certain quantity of purchased annealed malleable scrap and steel scrap will be used, as well as the regular foundry returns.

Piling

6. Pig iron is piled in as large piles as practicable, being unloaded and piled in horizontal layers. When being consumed the pig iron is loaded from the face of the pile so as to obtain an average of the entire pile.

Sampling and Analysis

7. Pig iron from each car is sampled in the proportion of one pig for every 10,000 lb. An equal amount of drillings is taken from each pig, mixed, and analyzed. The result is the car analysis. The average pile analysis is calculated from the weights and analyses of the cars in the pile.

8. Malleable and steel scrap are not analyzed but a constant figure is adopted for their analysis:

	Si, Per Cent	*Mn, Per Cent*	*C, Per Cent*
Malleable Scrap	0.90	0.30	2.00
Steel Scrap	0.20	0.40	0.20

These analyses may not be always exactly representative but as their effect is averaged in the following calculation, the difference from actual analysis is included in the normal variations and is therefore absorbed in the average loss figures.

Mixture Calculation

General

9. Although silicon, manganese, and carbon are all calculated, no special attention is given to manganese unless final analyses warrant it. This happens very seldom as long as pig iron manganese contents are within the normal range. Sulphur and phosphorus are checked on each heat but are not included in the calculation for the furnace charge.

10. Before starting to calculate the mixture the following figures must be at hand:

(a) The calculated analysis of the previous heat.
(b) The preliminary sample analysis of the previous heat.
(c) The final analysis of the previous heat. (This is the average analysis of three samples taken one at the beginning, one in the middle and one at the end of the heat.)
(d) The average loss in silicon and carbon from calculated analysis to preliminary analysis and from preliminary analysis to final analysis, calculated on the basis of the last six days.
(e) Analyses of pig irons and scrap.
(f) The desired final analysis.

Average Melting Loss

11. All of the figures mentioned in the foregoing paragraph should already be on record except the average loss figures which are made up each day. The last six heats form the basis for these calculations. That heat of the six which shows the highest loss is eliminated as being a possible exception and the average of the remaining five is taken as the predicted loss for the next heat.

12. These calculations are made daily, eliminating from the average the oldest heat of the six and adding in the new heat as shown in Table 1. In this table the figures in columns 1 and 5 are the differences between calculated analyses and preliminary sample analyses. The figures in columns 3 and 7 are the difference between the preliminary sample analyses and the final heat analyses. The figures in 2, 4, 6 and 8 are averages over the previous six days after the highest figure (in brackets) has been eliminated.

Record Forms

13. Tables 2 and 3 show the recto and verso of the mixture calculation

Table 1

MELTING LOSSES

Date	Silicon Loss*, Per Cent — Before Prelim. Analysis (1)	(2)	After Prelim. Analysis (3)	(4)	Carbon Loss*, Per Cent — Before Prelim. Analysis (5)	(6)	After Prelim. Analysis (7)	(8)
Nov., 1943	*Daily*	*5-Day Avg.*	*Daily*	*5-Day Avg.*	*Daily*	*5-Day Avg.*	*Daily*	*5-Day Avg.*
1	(0.49)	.....	(0.13)	....	(0.47)	.....	0.20	.....
2	0.27	.....	(0.09)	....	0.29	.....	0.24	.....
3	0.29	.....	0.03+	....	0.34	.....	(0.27)	.....
4	(0.39)	.....	0.04+	....	(0.39)	.....	0.14	.....
5	(0.30)	.....	0.00	....	(0.36)	.....	0.18	.....
6	0.18	0.286	0.01+	0.002	0.23	0.322	0.24	0.200
8	0.24	0.256	(0.06)	0.004+	0.33	0.310	(0.26)	0.212
9	0.25	0.252	0.02	0.012+	(0.33)	0.318	0.23	0.210
10	(0.29)	0.252	0.03+	0.012+	0.29	0.308	0.25	0.208
11	0.27	0.246	0.04+	0.012+	0.25	0.286	(0.28)	0.232
12	0.28	0.244	0.00	0.012+	0.26	0.272	0.24	0.244

*Plus marks indicate a gain instead of a loss.

sheet. On Table 2 are made all the loss calculations based on the previous six heats and on Table 3 the calculation of the mixture for the next heat.

14. Tables 4 and 5 show the recto and verso of the sheet sent to the foundry scale-house with only the percentage column and calculated analysis figures filled in. After the heat is poured, the sheet is returned to the laboratory with the rest of the information completed. Table 6 shows the daily heat record sheet which is compiled from all the forms already mentioned plus the analysis figures and the physical properties of the test-bars after annealing.

Table 2

LOSS CALCULATION

Date: Nov. 12, 1943. *Heat No. 1, Furnace No. 1*

	Per Cent Si	Per Cent C
Calculated Analysis	1.25	3.00
Preliminary Analysis	0.97	2.74
Loss Before Preliminary	0.28	0.26
Preliminary Analysis	0.97	2.74
Added Elements	0.05	0.00
Rectified Preliminary	1.02	2.74
Final Analysis	1.02	2.50
Loss After Preliminary	0.00	0.24
Avg. Loss Before Preliminary	0.244	0.272
Avg. Loss After Preliminary	0.012	0.244
Avg. Total Loss After Preliminary	0.232	0.516
Desired Final Analysis	1.000	2.500
Required Calculated Analysis	1.232	3.016

An Example of Mixture Calculation

15. The forms shown in Tables 1 to 6 represent the heat for November 13. The calculated analysis for the preceding day was:

Silicon, 1.25 per cent Carbon, 3.00 per cent

The analysis of the preliminary sample was:

Silicon, 0.97 per cent Carbon, 2.74 per cent

The analysis of the finished heat was:

	Silicon, Per Cent	*Carbon, Per Cent*
Bar 1	1.01	2.55
Bar 2	1.02	2.46
Bar 3	1.03	2.49
Average	1.02	2.50

16. An addition of one per cent of 50 per-cent-ferrosilicon was made to this heat and was taken into consideration in added elements in Table 2. As it is not always possible with the materials on hand to calculate a mixture exactly, a leeway of 0.02 per cent plus or minus is allowed on both silicon and carbon between the required and actual calculation.

17. As explained in paragraph 11 before figuring the average loss, the highest figure of the six is eliminated as a possible exception. It might be asked why the lowest figure is not also eliminated for the same reason. Only the highest figure was eliminated because this would throw the tendency towards heats on the low side for either silicon or carbon. These heats require furnace additions of small quantities of ferrosilicon with a rare occasion requiring carbon addition in the form of graphite or petroleum coke.

18. If the tendency of the heats were towards normal, an occasional heat might require some addition to lower carbon or silicon. The only material in such a case is steel scrap and additions of this material are so much heavier than the ferrosilicon additions and usually have such a cooling effect on the

Table 3

MIXTURE CALCULATION

Date: Nov. 13, 1943. Heat No. 1, Furnace No. 1

Mixture

Charging Material.	*Per Cent*	*Si*	*Mn*	*C*	*Si*	*Mn*	*C*
Pig Iron: Car No. A	19	1.40	0.80	4.05	0.266	0.152	0.770
Pig Iron: Car No. E	6	2.15	0.75	3.90	0.129	0.045	0.234
Pig Iron: Car No. D	21	1.35	0.85	4.10	0.284	0.179	0.861
Pig Iron: Special Sprue	10	1.70	0.45	2.40	0.170	0.045	0.240
Domestic Scrap	30	1.00	0.38	2.50	0.300	0.114	0.750
Bought Mall. Scrap	7	0.90	0.30	2.00	0.063	0.021	0.140
Steel Scrap	7	0.20	0.40	0.20	0.014	0.028	0.014
Calculated Analysis	.	....	....	....	1.226	0.584	3.009

bath that calculation formulas are purposely made to avoid them, even at the expense of ferrosilicon additions.

FURNACE CONTROL

The Melting Unit

19. In this particular foundry the charge is melted in a powdered-coal-fired air-furnace of about 20 tons capacity. Powdered coal is blown to the furnace from a central pulverizing system. The supply of coal is regulated at the furnace by means of remote control on the speed of a feed screw at the pulverizer unit. A small and constant quantity of primary air furnished by a fan-type blower at the coal pulverizer is used to blow the coal to the melting furnace. Secondary air is supplied at the furnace by means of a second fan-type blower with a circular shutter-type gate on the air inlet.

Table 4

MIXTURE

MALLEABLE FOUNDRY

Date: Nov. 13, 1943. Heat No. 1, Furnace No. 1

	Material	*Per cent*	*Weight, Lb.*
Pig Iron	Car No. A	19	6155
	Car No. E	6	1980
	Car No. D	21	7045
	Special Sprue	10	3300
	Domestic Scrap	30	9900
	Bought Mall. Scrap	7	2310
	Steel Scrap	7	2310

Cal. Analysis...............Si—1.23..................C—3.01...............

Weight of Charge	33,000	**Started Firing**	4:00 A.M.
Started Slagging	8:20 A.M.	**Preliminary Test**	9:25 A.M.
Loads of Slag	9	**Additions Made**	10:10 A.M.
Started Tapping	10:35 A.M.	**Finished Tapping**	11:15 A.M.

....

Signature

20. Figure 1 shows the burner end of the melting furnace with the switchboard controlling the coal- and air-feeding motors both at the pulverizer and at the furnace. The secondary air gate is also shown. The main objection to the type of coal feed and its control used in this installation is that the correlation between feed-screw speed and quantity of coal being delivered is far from constant, especially when there is a variation in coal fineness and humidity. Often visual appreciation of the proportions of coal to air was also found to be faulty. It was very difficult to control melting losses in silicon and carbon and especially in the latter. Melting time and pouring temperature also suffered from the same causes. This was found when it was attempted to

Table 5

FIRING SCHEDULE

Time	*Ratio Coal to Air*
4:00 A.M.	10:6
4:20	11:8
4:40	12:10
5:00	14:12
5:20	15:13

Additions

......99......lb. 50% Ferrosilicon
..............lb. Petroleum Coke
..............lb. Manganese Pig
..............lb. Steel Scrap

Table 6

MALLEABLE FOUNDRY

DAILY FURNACE REPORT

Date: Nov. 13, 1943. Heat No. 1, Furnace No. 1

Mixture

	Materials	*Per cent*	*Si*	*Mn*	*C*	*Si*	*Mn.*	*C*
Pig Iron	Car No. A	19	1.40	.80	4.05	.266	.152	.770
	Car No. E	6	2.15	.75	3.90	.129	.045	.234
	Car No. D	21	1.35	.85	4.10	.284	.179	.861
	Special Sprue	10	1.70	.45	2.40	.170	.045	.240
Domestic Scrap		30	1.00	.38	2.50	.300	.114	.750
Bought Mall. Scrap		7	.90	.30	2.00	.063	.021	.140
Steel Scrap		7	.20	.40	.20	.014	.028	.014
Calculated Analysis		.	....	....	....	1.226	.584	3.009

Weight of Charge........33,000........Started Firing..........4:00 A.M. ......
Started Slagging........8:20 A.M. ......Preliminary Test.......9:25 A.M. ......
Loads of Slag..............9..........Additions Made.....10:10 A.M. ....
Started Tapping...... 10:35 A.M. ......Finished Tapping......11:15 A.M. ......
Preliminary Analysis...........Si.......86..... Mn............ C.....2.69.....
Additions Made..................99 lb. of 50% Ferrosilicon..................

Remarks: Starting Schedule—

Time	Coal	Air
4:00	10	6
4:20	11	8
4:40	12	10
5:00	14	12
5:20	15	13

Final Metal

Bar No.	*Si*	*Mn*	*C*	*P*	*S*	*Mottle*	*Bar*	*Load*	*Elong.*
1	1.02		2.47			0%	1	....	....
2	.99	.30	2.47	.11	.07	0%	2	....	....
3	1.00		2.43			0%	3	....	....
Avg.	1.00	.30	2.46						

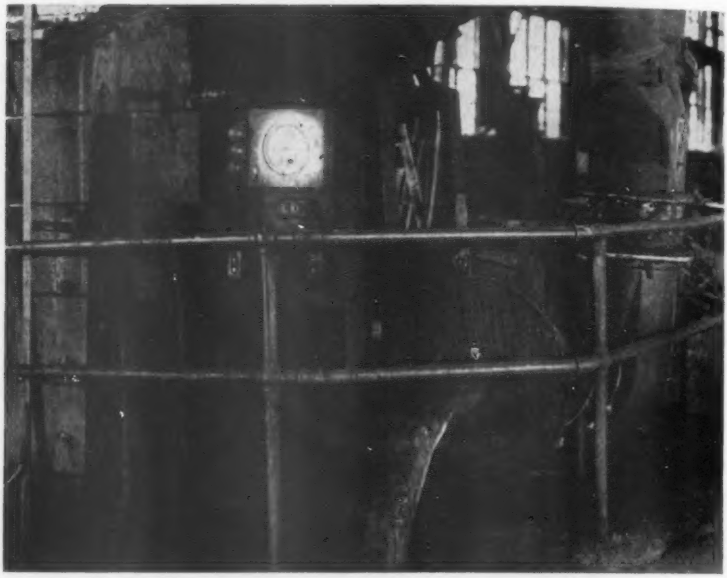


FIG. 1—BURNER END OF MELTING FURNACE AND CONTROL BOARD FOR COAL- AND AIR-FEEDING MOTORS.

control heats on the basis of some predetermined regulation of feed-screw speed and secondary air inlet. This method of regulation would not give duplication of results and was an utter failure.

Experimental Control

21. An attempt was then made to analyze the exit gases and to regulate coal-air ratios according to CO_2, O_2 and CO contents. The samples were taken through the side-wall of the furnace about six in. above the bath and about three ft. in front of the rear bridge-wall. The first analyses were made with a portable Orsat-type apparatus and considerable improvement was noted in the regularity of composition when firing by these indications. However it soon developed that without an experienced and conscientious operator on the gas analysis apparatus, very serious errors could be made.

22. It was also proved during this experimental period that inside-furnace pressure was necessary, not only to obtain a representative sample of gas, but also for best melting conditions. This furnace pressure could be controlled by varying either the secondary air or the stack draft. Stack draft was varied by increasing or decreasing an opening at the base of the stack. This experimental period then indicated two necessary and interdependent controls, inside-furnace pressure and exit-gas analysis. The indicators for these two quantities would have to be automatic, continuous, and as fool-proof as possible.

The Gas Sampling System

23. The experimental period showed there were two contaminations in the gas from the furnace, dust and condensable water vapor. A simple arrangement in the form of a water trap or seal placed at floor level was used to trap both dust and water. The temperature in this trap was low enough so that any water that did not condense here would not condense further on. The decrease in velocity was great enough to allow settling of enough dust so that the remainder did not interfere with gas analysis. The same gas outlet was made to serve both the gas analysis apparatus and the draft and pressure gauge. A sketch of the exit-gas line from furnace to instruments is shown in Fig. 2.

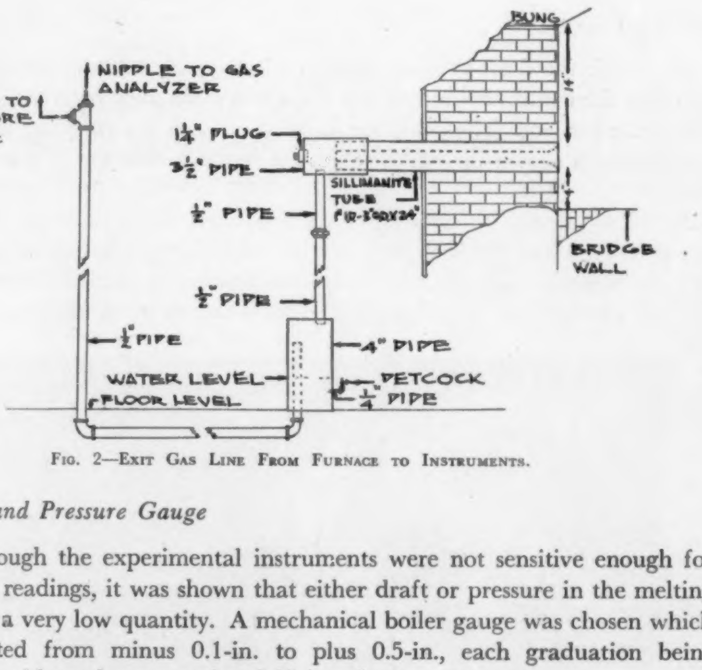


Fig. 2—Exit Gas Line From Furnace to Instruments.

The Draft and Pressure Gauge

24. Although the experimental instruments were not sensitive enough for quantitative readings, it was shown that either draft or pressure in the melting furnace was a very low quantity. A mechanical boiler gauge was chosen which was graduated from minus 0.1-in. to plus 0.5-in., each graduation being about ½-in. wide and representing 0.02-in. of water pressure.

The Gas Analyzer

25. During the experimental period of gas analysis it was found that the ideal conditions for melting were those which showed a slight excess of CO, from 0 to 4 per cent. Conditions often arose when there was an excess of O_2. The gas analysis indicator therefore had to show more than the CO_2 content. It had to show not only when the CO_2 content was low, but also whether this was due to excess air or excess coal. The apparatus finally chosen was

one of the thermal conductivity type such as that used to check motor combustion on motor cars and principally to indicate the correct gas-air ratio in setting carburetor adjustments. The dial of this apparatus was originally marked into three zones lettered *Lean, Normal,* and *Rich.* After a few weeks comparison between gas analyzer readings and practical results at the furnace, such as melting loss in carbon and silicon and tapping temperatures, it became evident that the spacing of the *Normal* zone would have to be changed from its original position. *Normal* firing in the air furnace proved to be much leaner than *Normal* combustion conditions in a motor car. This shift in the *Normal* zone was accomplished by simply applying a tricolored band relocating the limits of the three zones. From that time on, with very few exceptions, coal-air ratio was regulated according to the indications of the gas analyzer.

Melting Practice

26. With the draft-pressure gauge and gas analyzer installed and in working order the control apparatus was always in plain view from the switchboard side of the furnace. The complete installation with gas sampling tube and the instruments is shown in Fig. 3. Figure 4 shows a close-up of the two instruments.

27. The procedure on each heat was then the following: There is a period, from when the furnace is first lit until enough secondary air is applied and the furnace becomes hot enough to produce a pressure in the furnace, that the gas analyzer is inoperative. This is shown by the fact that the gauge

FIG. 3—GAS SAMPLING TUBE AND RECORDING INSTRUMENTS.

indicates draft instead of pressure. Even if a sample of gas could be taken by exhausting it from the furnace, it would not be representative of coal-air ratio at the burner because it would include air-induction through the doors and roof. During this initial period a definite coal-air setting schedule based on recent experience is used until the time when pressure is built up in the furnace and the gas analyzer starts functioning. This initial coal-air setting schedule is progressive and is recorded on the form shown in Table 5, as well as well as on the daily heat record sheet shown in Table 6.

28. As soon as the analyzer starts functioning, the powdered coal supply is so regulated as to keep the pointer of the analyzer within the *Normal zone*. The melter varies the intensity of firing by varying the secondary air settings which are left to his judgment, and he also has a leeway in coal regulation within the zone marked Normal. These conditions are maintained until the report on the preliminary sample is received from the laboratory.

Preliminary Sample Procedure

29. As soon as the first slagging operation is completed and the bath well mixed, a preliminary test bar is poured and sent to the laboratory for analysis. Only silicon and carbon are determined on this bar unless an exceptionally low silicon result indicates a highly oxidized heat. In this case the manganese also is determined. The test bar is cooled, drilled and analyzed and the result reported to the foundry. This result consists of the chemical determinations (usually only silicon and carbon), the amount and kind of additions if any,

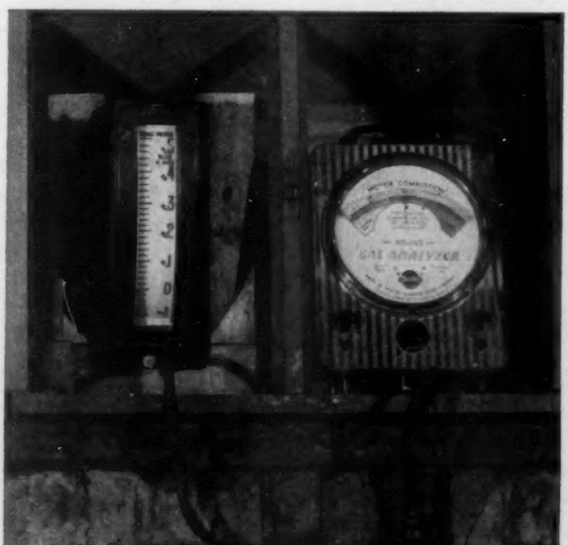


FIG. 4—CLOSE-UP OF DRAFT-PRESSURE GAUGE AND GAS ANALYZER.

and the firing method *(Lean, Normal or Rich)* to be used until the heat is tapped out.

30. The sampling and analysis under normal conditions require about twenty minutes and the choice and quantity of additions are read directly from the "Addition Computator" shown in Fig. 5. This "Addition Computator" is simply a device for rapidly indicating (a) when a chemical determination should be checked, (b) the choice and quantity of additions if any, and (c) the method of firing until the heat is tapped.

31. A short study of Fig. 5 will show how the computator is used. The two sliding scales are set so that the average loss figures after the preliminary are opposite the gauge marks. Then the preliminary sample analysis, silicon

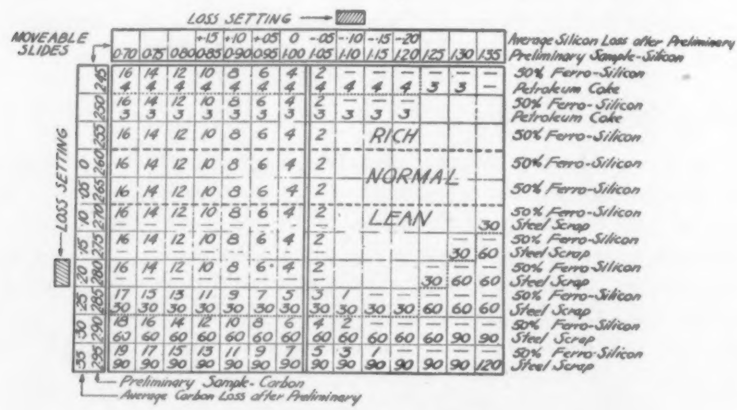


FIG. 5—ADDITION COMPUTATOR.

and carbon, determines one certain square in the center portion of the computator. The position of this square and the figures placed in it, or the absence of figures furnishes the rest of the information. This computator has the gauge marks set for 1.00 per cent silicon and 2.50 per cent carbon but can be set for any other desired composition by changing the position of the gauge marks. The figures in the squares are lb. per ton of furnace charge. The addition material referred to is shown at the extreme right. If any analysis falls in a square above the top dotted line or below the bottom dotted line, the carbon result must be checked. If any analysis falls to the left of the double solid line, the silicon result must be checked. If any analysis falls above the top broken line the furnace must be fired *Rich;* below the bottom broken line, *Lean;* and between the two, *Normal;* these three settings referring to the zones marked on the gas analyzer at the furnace.

CONCLUSIONS

32. Each melting unit has its own peculiar set of uncontrollable variables.

These variables are also unpredictable. Any prediction may result in double error if the prediction is false. If mixtures are so calculated as to always aim at the median point in the sum of the variables, extremes are thereby avoided. It has been shown that basing mixtures on the average of some determined period of immediately previous operation reduces extremes in chemical analysis from those obtained from mixtures based on personal prediction. It also throws this once very specialized work into the realm of ordinary arithmetic where it may be handled by help having little or no experience in either metallurgy or melting.

33. The coal supply from this particular pulverizer unit is not constant enough to regulate firing on the basis of feed-screw speeds. In this particular case this condition is due mainly to either a variation in coal humidity or mechanical defects, but could also be caused by variations in coal fineness or available calorific value. As all of these variables can also be present in unit pulverizers, it is possible that the same variation applies.

34. Visual observation of the aspect of the flame is frequently not accurate enough to be used as a basis for coal-air ratios.

35. With very few exceptions the analysis of a representative sample of exit-gas from a powdered-coal-fired air-furnace will indicate the coal-air ratio.

36. Slight but definite inside-furnace pressure is necessary to obtain a gas sample representative of coal-air ratios at the burner. Any depression in the furnace allows the admixture of air through doors and roof and falsifies the result. .This slight pressure has also been found to accompany best melting practice.

37. Control of coal air ratios, has its main effect on carbon control. Comparison of two six-months periods, one with and one without gas analysis control, showed that the average steel additions to reduce carbon in heats where carbon was too high were reduced from 12.7 to 1.6 lb. per ton and at the same time coke additions were reduced from 1.2 to 0.6 lb. per ton.

DISCUSSION

Presiding: A. M. FULTON, Northern Malleable Iron Co., St. Paul, Minn.

Co-Chairman: F. L. WOLF, Ross Tacony Crucible Co., Tacony, Philadelphia, Pa.

J. N. JOHNSON[1]: Have you ever attempted to adjust the flame by the use of an optical pyrometer?

MR. MCKINNEY: That would give only temperature; it would not indicate gas properties.

MR. JOHNSON: Is there no relation between the temperature and the CO_2 ratio?

MR. MCKINNEY: I have never attempted to determine it, but I would not think that there would be any relation.

D. TAMOR[2]: Referring to the exit gas line sketch (Fig. 2) I would like you to follow those gases through. You do not show any water cooling there.

MR. MCKINNEY: No. It has been found that with this type of gas analyzer, the speed of flow through the line is so slow that any amount of heat present will not cause any serious difficulties with the gas analyzer. Also, the speed is so slow that a certain amount of powdered coal sometimes will collect in the bottom and, being trapped in water, it is not carried to the instrument.

MR. TAMOR: In other words, that is really a closed system.

MR. MCKINNEY: It is a closed system.

MR. TAMOR: The idea of the water trap is to trap all of the solids.

MR. MCKINNEY: That is right.

MR. TAMOR: The joint on top where the sillimanite tube meets the iron, is that a cemented joint?

MR. MCKINNEY: Yes. The fact of the matter is, it would not make any difference if it were not closed, because as we are working under pressure, there cannot be any infiltration. If there is any movement, it is outward and not inward.

MR. TAMOR: In relation to the door, where is that tube?

MR. MCKINNEY: This tube is at the rear of the furnace, 3 ft. in front of the rear bridge wall.

H. E. LEICKLY[3]: In this idea of using the pulverizer with the CO and CO_2 determinations, you would use that as a means for checking the silicon and carbon reduction. Now, when your melter gets to the point where his charge is completely melted and he has skimmed the bath and it is coming time to pour, then you forget that and you start firing heavier to get the temperature up to where you want to bring the metal out?

MR. MCKINNEY: Oh, no. The computator indicates to the melter whether he shall fire rich, normal or lean, but he can regulate the intensity of his firing by the amount of secondary air. He can increase the secondary air, but the moment he does, naturally, the gas analyzer is going to show he needs more coal at the same time. The gas analyzer only shows the relationship between air and coal but not how much of each one should be used.

MR. LEICKLY: You take preliminary checks through a test plug and a skim-over test?

MR. MCKINNEY: Right.

---

[1] Union Malleable Iron Co., Moline, Ill.
[2] American Chain & Cable Co., York, Pa.
[3] Fanner Mfg. Co., Cleveland, Ohio.

R. F. GREENE[4]: What has been found to be the ideal melting analysis of the gas?

MR. MCKINNEY: The ideal melting analysis of the gas runs between 2 and 4 per cent CO.

MR. GREENE: Throughout the entire heat?

MR. MCKINNEY: Throughout the entire heat. With the method of calculation being used here, the method of mixture calculation, it does not make any difference. If you prefer to use nothing to 2 per cent CO, you will simply find the drop in carbon is more and, as we work on the average loss, this will be compensated in the mixture afterwards by simply putting more carbon in to take care of it. But we have found that the best results in melting come by using between 2 and 4 per cent CO.

D. F. SAWTELLE[5]: Do you not notice a change in the carbon content, even though you are keeping a 2 to 4 per cent CO content, if your pulverization of the coal changes?

MR. MCKINNEY: Within the limits that we have, no. We have several times measured the coal fineness and we always have at least 80 per cent through a 200 mesh.

D. LEVINSON[6]: You take your gas sample 3 ft. inside the bridge wall (Fig. 2). What prompted you to put it just at that point?

MR. MCKINNEY: Just chance. The first time that we took the sample, there happened to be a hole underneath the bung where the melter heats bars for forging, so we put the trap there and it seemed to work.

MR. LEVINSON: Do you not feel that the CO-CO_2 ratio changes with temperature? That is, where the flame hits directly over the bath, you get a different temperature than you would in the end of the furnace, and I think you should get a different CO-CO_2 ratio there.

MR. MCKINNEY: It is not the CO-CO_2 ratio which changes, but the oxidizing effect of the CO-CO_2 ratio changes with temperature. It should be complete. The reason that we took it at that point was that we figured the farther back in the furnace, the more chance there would be of complete raction.

MR. TAMOR: In regard to that pressure gauge, do you use that for a control as to how much pressure you want in the furnace?

MR. MCKINNEY: Yes. We consider that we must have at least 0.02 in. pressure. This is all that is necessary.

MR. LEICKLY: When do you make the first test?

MR. MCKINNEY: We make the first test just as soon as the pressure indicator shows that we have pressure inside the furnace. At that moment, the apparatus is turned on and the needle works continually all the time through the heat.

MR. LEICKLY: Just what is the state of your bath when that test is made?

MR. MCKINNEY: It has barely started to melt.

MEMBER: I might drop a word of caution there, in case anyone wants to duplicate that. The length of the pipe and the diameter might vary that pressure a little bit.

MR. MCKINNEY: In this instance, you have two instruments on the one pipe and, naturally, the cross section of the pipe must be decidedly greater than the outlet of the two nipples that go into the instruments to have pressure ditribution to both of them.

MR. TAMOR: You could have a "Y" fitting.

MR. MCKINNEY: The disadvantage of having a pipe too large would be that the time from the furnace to the analyzer would become greater. There would be a lag

[4] Detroit Brass & Malleable Works, Wyandotte, Mich.
[5] Malleable Iron Fittings Co., Branford, Conn.
[6] Acme Steel & Malleable Iron Works, Buffalo, N. Y.

from the furnace to the analyzer. In this case, we find that when we make a change in coal regulation, for that change to be registered on the gas analyzer takes something like 2 to 3 min.

C. R. WIGGINS[7]: Do you get better castings after annealing by the use of this control during melting?

MR. McKINNEY: More uniformity in composition, yes.

MEMBER: You put this analyzer to work right after you are through the pulsating period in the furnace that occurs after the charge is melted down?

MR. McKINNEY: That is right.

MEMBER: And after that, you keep a constant pressure on it.

MR. McKINNEY: As to pressure regulation, there is a damper or an intake at the base of the stack which regulates the draft in the stack, and if it is desired to increase pressure in the furnace, it is necessary only to decrease draft in the stack.

MEMBER: Can you correlate your loss in carbon with so many sq. ft. of furnace area or draft area per hour?

MR. McKINNEY: I have never tried it.

MEMBER: You can get so much carbon drop in a certain length of time on that furnace with a CO_2 of 2 to 4 per cent.

MR. McKINNEY: The drop in carbon is much more rapid while melting down than it is while superheating; and it is also much more rapid on a first heat than on a second heat. So there is not any direct correlation.

MR. LEICKLY: Under these conditions, then, what would be the character of the flame as you look at it in the furnace? Can you look across from one side to the other?

MR. McKINNEY: Sometimes we can and sometimes we can not. We may have a flame that we can see right through the furnace to the other wall, and at other times we can not see through the flame. That is just the point that is brought out. We can not tell by visual observation.

MR. LEICKLY: How do you account for that?

MR. McKINNEY: By the fact that the flame in one case has more luminous gases in it than it does in another.

MR. LEICKLY: There would be a more luminous flame when more coal was going through.

MR. McKINNEY: Quite possible, but this does not indicate gas composition. There were times when gas analysis showed that firing was normal and when it would seem from looking at it that the flame was not right.

MR. LEICKLY: Was not hot enough; you could see right across the furnace.

MR. McKINNEY: Yes. But we found that the gas analyzer knew more about it than we did.

MR. LEICKLY: Do you have to have the flame come out a couple of ft. on the side of the furnace to do this?

MR. McKINNEY: Usually, we do; we have the flame coming out the side of the furnace. That is a question of furnace pressure.

MR. LEICKLY: In working the furnace under pressure, then, your refractory cost must be much higher than prior to using your gas analyzer.

MR. McKINNEY: No. It is not pressure that uses refractories; it is velocity of gases

[7] Ferrous Metals Corp., New York.

passing them. When I say "pressure," it does not amount to much as it is only 0.02 in.

MEMBER: You say you have the flames coming 1½ to 2 ft. outside of the furnace. You have to put quite a lot of pressure on to get that.

MR. MCKINNEY: I believe that there are a lot of furnaces where you will see it flying out that far.

MEMBER: When you are melting the stock down, do you not think it is the pressure that is in the excess heat and the fact that the flame can not get past the masses of metal, rather than velocity of gases, that is burning out your side walls?

MR. MCKINNEY: Well, it has to go past the charge anyhow before it gets to the door, so whether it comes out the door or somewhere else does not make any difference.

MEMBER: But if you do not hold so much pressure on there with your higher heat in your melting down process, you will have a lower refractory cost.

MR. MCKINNEY: I do not know. We have not noticed that.

CHAIRMAN FULTON: Did you have much difficulty in training your furnace men, after you had installed this apparatus, to cooperate in using the apparatus?

MR. MCKINNEY: I must admit that it took a fair bit of applied psychology. I told the melter that I did not think that the apparatus was worth much and not to pay any attention to it at all, but just to go ahead and fire as he would. But curiosity gets the better of us all, and one day he said, "You have something on your mind. What do you think it shows, anyhow?"

I said, "I do not know whether I am right or not, but you watch and find out. If you run all day with the needle over on the rich side, you are going to come out wtih your preliminary analysis too high in carbon and you are going to have to put a lot of steel in that mix and you are going to have a lot of work. On the other hand, if you run it clear down on the lean side, you are going to burn your heat and you will get into trouble. That is what I think it shows. I am not sure. You watch and find out."

The effect of that was that about two months later he came to me and said, "How do you expect me to melt this heat? The analyzer is not running; the battery is out today; it will not run."

C. C. LAWSON[8]: From the time that the heat is tapped, do you notice a pick-up or loss either in silicon or manganese?

MR. MCKINNEY: Sometimes we have a pick-up in silicon. Sometimes we have a drop in silicon. We always have a drop in carbon.

MR. LAWSON: Did I understand you to say that you had a greater loss of carbon during the melting than during the superheating?

MR. MCKINNEY: Yes, always.

MR. LAWSON: I have always found the opposite to be true.

MR. MCKINNEY: What period do you refer to as melting down, up to what point?

MR. LAWSON: Up to when it is all melted.

MR. MCKINNEY: We do not know until we take the preliminary analysis. Our melting down time is up to the preliminary analysis.

MR. LAWSON: You take the preliminary analysis shortly after everything is melted, do you not? If you wait until the time you tap it, that is different. I was thinking of taking a preliminary when the iron had become sufficiently hot to dip a sample.

MR. MCKINNEY: You might be right in that case, but I think that would be taking the preliminary too soon for the best practice. We usually wait until the iron is much

[8] Wagner Malleable Iron Co., Decatur, Ill.

hotter than that before taking the preliminary; and if we wait until that point, we find that the loss is two times as much up to that point as it is after that point.

MR. LAWSON: I believe you are right if you wait until the iron is hot before you take the preliminary. Then, I would agree with you. If you take it shortly after it is melted, I would not.

MR. MCKINNEY: If you take the sample too soon, you stand quite a large chance that the bath is not properly mixed and you may get a sample that is not representative of the whole heat, which may induce an error.

MEMBER: Does your melter draw preliminary sprues and break them for preliminary examination?

MR. MCKINNEY: He does not break any more. I did not tell him not to; he stopped of his own accord. His interest in breaking one of them and looking at it was so small that he wanted to save himself the labor of pouring a second one, so he only pours one for the laboratory, because he does not care what it looks like. He gets the analysis back.

MEMBER: Before you had this analyzer, what did he do?

MR. MCKINNEY: Before, he used to pour two sprues.

MEMBER: Then he did not take them at perhaps ½-hr. intervals.

MR. MCKINNEY: He only took them at one definite point.

MEMBER: Some people do believe in taking a series of four or five sprues and watching them as the changes are taking place.

F. J, WURSCHER[9]: What is the size of the furnace that you are using, with regard to tonnage, and did you notice if, by the use of this method, you had a difference in the melting down period?

MR. MCKINNEY: The melting furnace is a 20 to 25-ton furnace. I can not say that any definite difference was noted in the melting down period, because we can melt down satisfactorily within different variations of CO-CO_2 balance that are not great enough to cause a great difference in melting down time but are great enough to cause a difference in drop in carbon content.

MR. WURSCHER: What is the furnace melting rate per hour?

MR. MCKINNEY: On a morning heat, it is about 22 or 23 min. to the ton. On the afternoon heat, it is about 13 or 14 min. to the ton.

---

[9] Chicago Railway Equipment Co., Marion, Ind.

Hardenability of Some Cast Steels

By J. B. Caine*, Lockland, Ohio

Abstract

Because of the increasing use of heat treated steel castings, the hardenability of cast steel has become important. The fundamentals of why steel hardens when quenched, and the reasons for the adoption of a new test to measure hardenability are discussed. The results of an investigation to determine the hardenability of some cast steels, and the correlation of these results with those of wrought steels are reported. The actual results are also checked with those obtained, theoretically, from the chemical analysis.

Introduction

1. Although the term hardenability is very new, the property in steel that it measures is as old as the art of steel making. This property has had many names, probably the most common of which were "timbre, body and personality," terms used continually by the older toolmakers. This property was, to these men, a very mysterious one, and was an unknown quality of the steel that defied control by ordinary chemical analysis or by temperature control during the heat treatment used in those days.

2. This mysterious quality can best be shown by comparing two small bars of 1.0 per cent carbon tool steel, of identical analysis as to carbon, manganese, silicon, sulphur and phosphorus contents, both being quenched in water at the same time after heating in the same furnace. When these bars are broken it will be found that the amount of energy required to break them and the grain appearance of the fractures are entirely different. Even though the surface hardness of the tough bar is slightly higher than that of the brittle bar, the brittle bar will break easily, showing a course-grained fracture, while the tough bar is fine grained and requires many times the energy to break it than does the coarse-grained bar.

3. Although a fine-grained steel is tougher than a coarse-grained steel, this fact is not sufficient to explain the great difference in toughness. If these bars are sectioned and a hardness survey made through the sections, the reason for the difference is very clear. Figure 1 shows the hardness of two such bars. Rockwell C hardness readings have been taken at 1/16-in.

---

*Metallurgist, Sawbrook Steel Castings Co.

Note: This paper was presented at a Hardenability and Heat Treatment of Steel Castings Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 27, 1944.

intervals across the sections and the readings plotted. This hardness survey shows the surprising fact that even though the surface hardness of the bars is almost identical, the hardness at the center of the sections is entirely different.

4. In the case of the coarse-grained steel, the bar has hardened at the center to 64 Rockwell C hardness, while the center of the fine-grained steel has hardened only to 43 Rockwell C hardness. This is the reason for the great difference in toughness. The tough, fine-grained steel is, in reality, similar to a carburized steel with a hard case and a relatively soft core, the soft core requiring a great deal of energy for rupture.

5. In other words, these two pieces of steel have different hardenabilities; the difference in hardenability, in this case, being due to austenitic grain size. Grain size is only one of a number of variables that influence hardenability. A great deal of work has been done in this country in the past ten years to find out not only what these variables are, but also to measure them quantitatively, and to find out from the theoretical standpoint, why these variables do affect hardenability.

Quantitative Measurement of Hardenability

6. First a word regarding the importance of measuring hardenability quantitatively. In the first place, when a casting is cooled at a rate much faster than in the furnace, the hardness at the surface is not a criterion of the hardness at the center of the section. A horrible example is, of course, the two bars shown in Fig. 1. This means that a design based on the strength corresponding to the surface hardness is weak, as the average strength of the section is much lower.

7. Then, it has been shown, at least for hot-worked steel, that a steel not

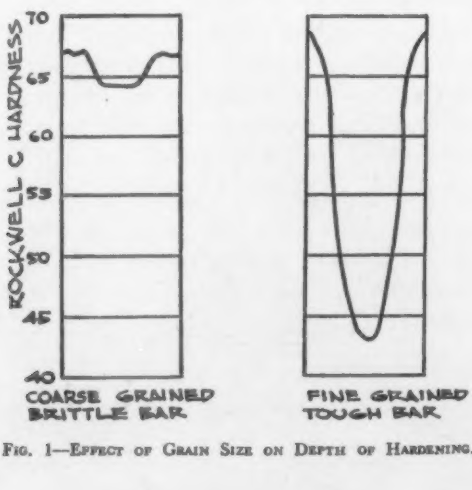


FIG. 1—EFFECT OF GRAIN SIZE ON DEPTH OF HARDENING.

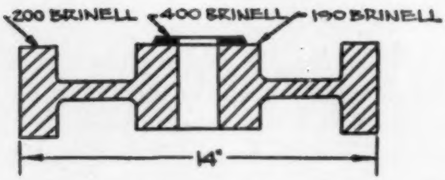


FIG. 2—CROSS SECTION OF CAST STEEL GEAR SHOWING NON-UNIFORM HARDENABILITY.

fully hardened is notch sensitive, as measured by the impact test, because of its microstructure. In order to obtain maximum resistance to notch sensitivity, it is necessary to fully harden the section throughout on the quench, regardless of the hardness required after the draw.

8. This property assumes even more importance, as in the case where a slight difference in hardenability can mean the difference between hardening even the surface and not hardening. Figure 2 shows an example. This gear had been made for years from S.A.E. 1040 steel, water quenched to 400 BHN. and drawn to 250 BHN. Suddenly, the gears would not attain even a 250 BHN., even when brine quenched. To make matters worse, when a hardness survey was made on this gear, it was found that they were not hardening uniformly. The little finish pad on the hub, as shown in Fig. 2, hardened to 400 BHN., the hub itself to only 190 BHN. This meant that the gear had to be drawn to soften the pad enough to make it machinable, and in so doing softened the rest of the gear so much that it had to be scrapped.

9. The reason for this, as will be shown later, was a decrease in residual elements in the steel. Because of an intensive drive to conserve alloys during the war, the small percentages of nickel, chromium and molybdenum in the steel had decreased to almost zero. Increasing the carbon content of the steel by 0.10 per cent was sufficient to eliminate the trouble. This example, although unusual, exemplifies how important hardenability can be and how small changes in hardenability can mean the difference between acceptance and rejection.

10. Davenport and Bain[1] and others have investigated and shown the fundamentals of why steel hardens, and have shown what is even more important—how to obtain quantitative data showing just how to quench to obtain a given hardness. The method of obtaining these data is simple, but very laborious. Literally, hundreds of samples are quenched from the hardening temperature, not to room temperature but to various elevated temperatures. and held at these temperatures for periods of time varying from a fraction of a second to weeks. When this is done, "S" curves like that shown in Fig. 3 are obtained. These curves are quite complicated, and some portions are not fully understood as yet. However, two points shown by these curves are very important.

[1]Superior numbers refer to references at end of this paper.

Cooling

11. In order to fully harden, the steel must be cooled at a rate that will pass between the ordinate and the nose of the "S" curve. For the particular steel shown, the limiting time is that between points "A" and "B" in Fig. 3, and all parts of the section must be cooled to below 1200 °F. in less than one second. After the section has been cooled through this range the cooling rate can be decreased tremendously, and the part will be just as hard as if it had been cooled to room temperature at the same rate it passed the nose of the "S" curve. This means that, for this particular steel, if it be quenched in lead at 700 °F. and, after it has reached 700 °F., allowed to cool in air to room temperature, it will be just as hard as if it had been quenched in brine all the way to room temperature.

12. The second important point is that any change made to increase the hardenability of steel merely moves the nose of the "S" curve (point B) to the right and allows more time for the steel to get past the nose on cooling. If the cooling rate is slowed up, because of either the quenching medium or size of section, it is possible to fully harden with this slower cooling rate.

Grain Size and Chemical Composition

13. There are any number of variables affecting hardenability, or the relation of points "A" and "B" in Fig. 3. Two major variables are grain size and chemical composition. It is well known that chemical composition determines how a steel will harden, but it has not been known until recently just how it affects hardenability. That is, we have not had quantitative information.

14. The effect of grain size is of prime importance to the steel foundryman. There are many ways to change the grain size of steel but, from the practical viewpoint of the foundryman, the most important is the aluminum content of the metal. Many foundrymen think of aluminum solely as a control for porosity and neglect its profound effect during heat treatment and on the physical properties, especially notch sensitivity or impact strength. Its effect on hardenability is so great that the hardenability of an aluminum-killed steel cannot be compared with the same steel without aluminum present in the metal. In fact, the sole difference between the two bars of tool steel shown in Fig. 1 can be a matter of 0.01 or 0.02 per cent aluminum in the steel. The coarse-grained, brittle, fully hardened steel can be a silicon-killed steel, no aluminum added; 0.01 per cent residual metallic aluminum in the same steel changes it to a fine-grained, tough, shallow hardening steel.

15. Grossmann[2] and Crafts and Lamont[3] have determined quantitatively the effect of grain size and composition on hardenability. It is now possible, from their curves, to calculate the hardenability of any analysis and grain size without even making the steel. Unfortunately, this work has been confined solely to hot-worked steels; no work has been done on cast steels.

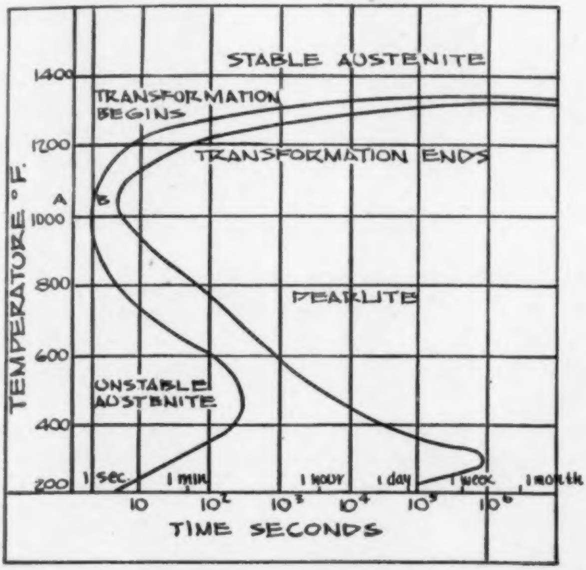


Fig. 3—"S" Curve for 0.80 Per Cent Carbon Steel (Simplified).

Again, this test is too laborious to be used as a production control. It involves hardening a number of section sizes from each analysis and grain size and determining the section size when the steel just hardens throughout the section. As the specimens must be sectioned in the hardened state, they cannot be sawed or machined, but must be cut with a cut-off wheel. This requires elaborate precautions so that the cut-off wheel does not heat and temper the specimen.

End-Quench Hardenability Test

16. Jominy and Boegehold[4] then introduced a simple test for hardenability that is ideally adapted to production control. Instead of hardening the whole section, only the end of the specimen is in contact with the quench, a stream of water. Hardness readings taken longitudinally along the surface of the bar will give the hardness of the steel from that equivalent to a drastic quench to that of an air quench as the distance from the water-cooled end increases. The cooling rates at all distances from the water-cooled end have been determined. The work of Scott[5] correlates these cooling rates with the cooling rates at the center of simple sections, quenched in different quenching media. Field[6] has correlated, at least partially, the results of the end-quench test with those of Grossmann[2] on the effect of composition and grain size. As we know the cooling rates throughout the length of the bar, we can apply all the information available in the "S" curves.

17. The end-quench test is, then, a key to unlock the door to a world of

knowledge as to the behavior of cast steels on quenching. Details of the end-quench specimen and fixtures are shown in Fig. 4. The drawing is self-explanatory. The simple test specimen is heated to 75 °F. above the A_{c3} point, held for 20 minutes and quenched cold in the fixture. The test is now a standard of the American Society for Testing Materials. Further details can be found in A.S.T.M. Specification A 255-42T.

SCOPE

18. As all published information on hardenability has been restricted to forged and rolled steels, the hardenability of some cast steels was investigated. These tests were made not only to determine the hardenability of these particular steels, but also to correlate the hardenability of cast steels to that of forged and rolled steels so that the mass of information now available on these hot-worked steels could be applied to cast steels. Then, too, these tests were made as a basis of comparison for future tests on the effect of the new, complex hardenability additions that are coming into use.

EXPERIMENTAL PROCEDURE

19. Tests were made on 11 types of cast steel. Five to 15 specimens of

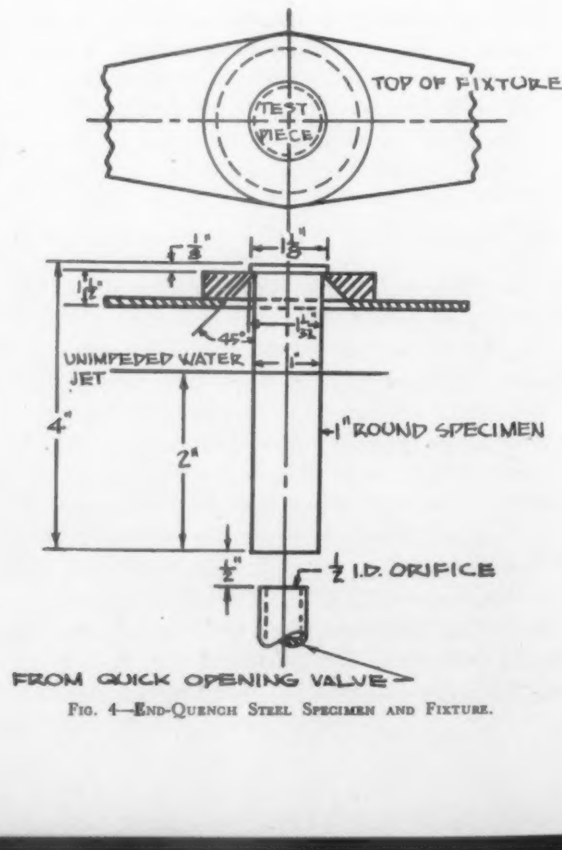


FIG. 4—END-QUENCH STEEL SPECIMEN AND FIXTURE.

each type were tested. Test coupons were selected at random from production heats made over a period of 2 years. The standard test procedure was used throughout, with one exception. As the only water supply available was tap water, the temperature range of the quenching water varied from 60 °F. to 75 °F. instead of the standard range of 75 °F. ± 5 °F. As will be shown later, the results check very closely with the hardenability calculated from composition, so that the error from use of the colder water must be inappreciable. If this colder water does have any effect, the hardenability should be slightly high.

20. The specimens were heated for hardening in an electrically heated laboratory furnace. It was found that if the specimens were placed in the furnace with the end to be quenched on a fire brick, that this end was only discolored, not scaled. Therefore, packing in cast iron turnings was dispensed with.

EXPERIMENTAL RESULTS

Carbon Cast Steel

21. The hardenability ranges for carbon cast steels are shown in Fig. 5. These curves, and all other curves in this report, are only representative of fine-grained aluminum-killed cast steels, A.S.T.M. grain size 6 to 8. The ranges shown are established by the analysis of the specimens tested. Theoretically, if an infinite number of specimens are tested, the results would not be separated in groups for each analysis, but there would be a continuous field of results from the lowest carbon to the highest, although the shape of the curves would be the same.

22. The dotted line in Fig. 5 shows the average hardenability of S.A.E. 1040 rolled steel, as published by the American Iron and Steel Institute[7]. The hardenability of this hot-worked steel is slightly lower than that of the comparable cast steel. This same relation holds true for alloy steels, as will be shown later. The difference is the result of the slightly higher silicon and residual aluminum contents of cast steels. The theoretical increase in hardenability resulting from the additional 0.20 per cent silicon and 0.02 per cent residual aluminum is about 14 per cent. This is equivalent to an increase of 8 to 13 per cent in the Rockwell C hardness of the end-quenched specimen. This increase in hardness appears some distance away from the quenched end where the alloys control hardenability. The actual increase in hardness and the location of the increase depend on the hardenability of the individual steel.

23. Note that the hardness of these carbon steels drop off sharply very close to the water-quenched end, about ⅛-in. away from the end. The correlation between the distance from the water-quenched and the hardness at the center of simple sections is shown at the top of these charts. As can

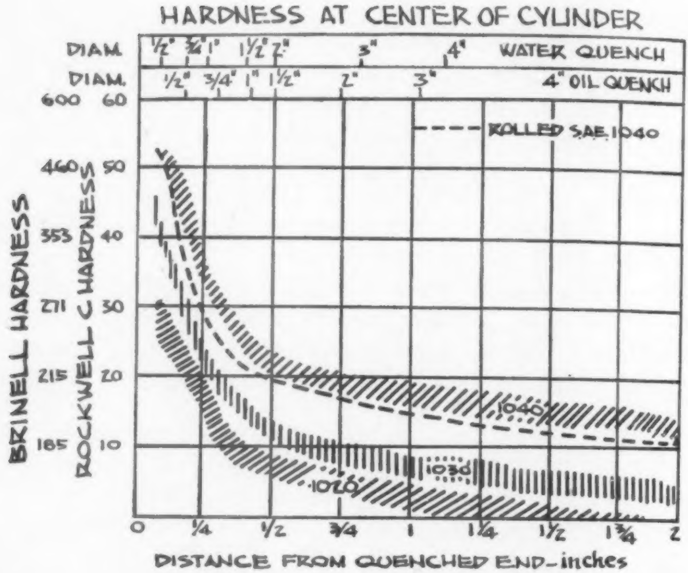


FIG. 5—HARDENABILITY OF CARBON CAST STEELS.

be seen, only a ¾-in. round will harden throughout when quenched in water, only a ¼-in. round in oil, if they be made of carbon steel.

Chromium-Molybdenum Cast Steel

24. Figure 6 shows the hardenability ranges for S.A.E. 4100, chromium-molybdenum cast steel. The dotted lines are the average hardenabilities for rolled S.A.E. 4140 and x4130 steel, as reported by the A.I.S.I. Again, the average hardenability, away from the quenched end, of cast steel is greater than that of hot-worked steel of the same carbon and specified alloy content.

25. There are two very important points brought out by comparing Figs. 5 and 6. The first is that the addition of alloys to a carbon steel does not increase the hardness. All they do is to increase the depth of hardness, that is, the hardenability. This point is shown in these two charts. The hardness at the water-cooled end is the same for S.A.E. 1040 as it is for S.A.E. 4140. With cooling rates as high as are present at this point, the carbon is the only variable controlling hardness. In other words, this part of the bar was cooled at a rate fast enough to pass the nose of the "S" curve for 0.40 per cent carbon steel. All that chromium and molybdenum do is to move the nose of the "S" curve to the right and allow more of the test bar to pass to the left of the nose. This fact is too often overlooked, even by metallurgists, and can stand repeating. Carbon is the only element in steel that gives hardness; alloys only increase hardenability.

Effect of Section Size on Hardenability

26. As can be seen from Figs. 5 and 6, S.A.E. 1040 and 4140 have about the same hardness up to a ¼-in. section quenched in oil, or a ⅝-in. section quenched in water. If the section is any larger, the hardness of the 1040 steel falls off rapidly, while that of the 4140 steel is still above 450 BHN. at the center of a 2-in. round quenched in water, and above 350 BHN. at the center of a water-quenched 4-in. round.

27. As was shown in the case of the gear, this difference in hardenability also shows up on the surface. If the 2-in. round be made of S.A.E. 1040 steel, only the corners would harden in water; the surface midway between the ends of the cylinder would show soft spots on the surface. A casting more complicated than a cylinder will be hard at one point and soft at another, about the worst condition that can happen.

Chemical Composition Control of Alloy Cast Steel

28. The other point is brought out by comparing the width of the hardenability fields in Figs. 5 and 6. When alloy castings are to be heat treated, the chemical composition must be controlled to within much closer tolerances than are necessary for slowly cooled castings, or even heat treated carbon steel castings, if the hardenability is to be controlled to within reasonable limits.

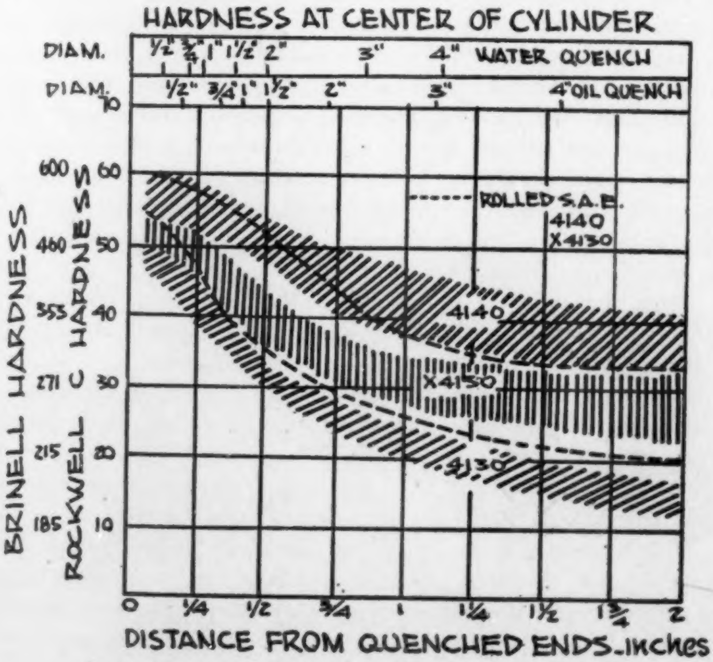


FIG. 6—HARDENABILITY OF CHROMIUM-MOLYBDENUM CAST STEELS.

29. This point is explained by the fundamental fact advanced by Grossmann[2] in his work on the effect of composition. The theory is that the hardening effect of each element present is not additive, but that the hardenability factors must be multiplied. Then, the higher the hardenability of the steel, the greater the effect of slight variations in all the elements present and the greater the effect of uncontrolled residual elements present.

30 This is very important in foundry practice, and will probably mean a different scheme of alloying than is used for the larger heats in the rolling mills. The small, fast-melting units in the steel foundry do not allow sufficient time for the laboratory to determine the residual alloy content of the heat after melt down. This is the only practical method of controlling these elements; they cannot be controlled successfully by analysing the scrap before charging.

31. What the foundry can do is to select analyses where variations in residual alloys are minimized; analyses not dependent on a single alloy for hardenability, but on two or three, preferably those that are likely to be in the scrap and are not oxidized and removed during melting. This is advisable, not only for alloy conservation and cost, but from a strictly quality standpoint.

Hardenability of Nickel Carburizing Cast Steels

32. This is brought out by the hardenability range curves for nickel carburizing steels shown in Fig. 7. Note the large spread in the hardenability results. The hardenability of these steels depends on large percentages of one alloy, nickel. The hardenability factor for 3.50 per cent nickel content is about 2.40. Even 0.05 per cent residual molybdenum will raise this factor to 2.76; 0.10 per cent chromium with the molybdenum will raise it to 3.45, a total increase in hardenability of 44 per cent. If the steel had a lower nickel content, with chromium and molybdenum added intentionally, the same variation in chromium and molybdenum would cause a much smaller variation in total hardenability.

33. From the practical standpoint of the foundry, it would seem that the content of each alloy should be controlled between 0.50 and 1.00 per cent. If any one alloy content is much more than one per cent, the effect of traces of other alloys present is too great, as was shown for nickel. If the content of each alloy is kept to less than 0.50 per cent, small, unavoidable variations again have too great an effect, due simply to percentage variation. A variation of 0.10 per cent is 25 per cent if the total content is 0.40 per cent, and only half of that if the total content is 0.80 per cent.

34. This suggestion is similar to that now used for the present "National Emergency" steels. It differs from these steels in that fewer alloys but slightly higher percentages of the individual alloy are used. The total alloy content is no greater than is present in the current "National Emergency" series of hot-worked steels.

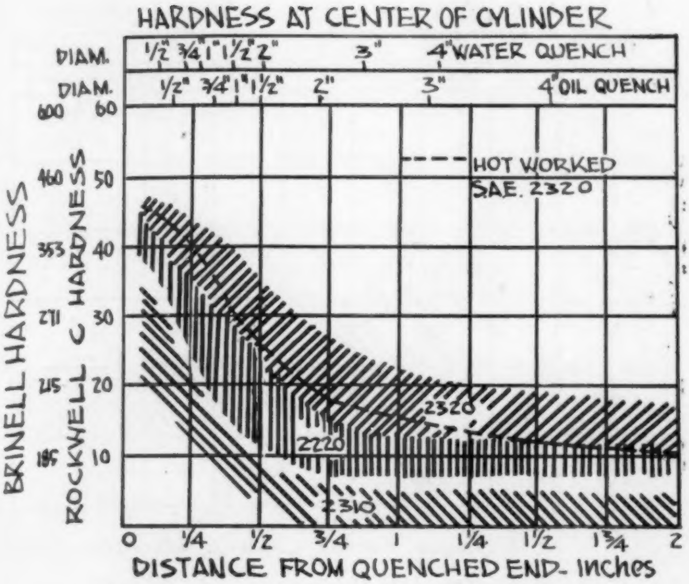


Fig. 7—Hardenability of Nickel Carburizing Cast Steels.

35. The substitution of 3.30 per cent nickel by 1.50 per cent nickel and 0.20 per cent molybdenum will give the same hardenability and be much less sensitive to variations in residual molybdenum. It also offers the advantage of lower cost and better machinability. An increase in the manganese content or the addition of chromium can further reduce the amount of nickel and molybdenum required.

Hardenability of Medium Manganese Cast Steel

36. Figure 8 shows the hardenability range curves for medium manganese steel with 0.30 per cent carbon and 1.50 per cent manganese. The comparable curve for rolled steel is, in this case, slightly higher than the average for cast steel. This is because the S.A.E. 1330 rolled steel is slightly higher in manganese, i.e., 1.60 to 1.90 per cent manganese.

37. This chart (Fig. 8) again shows, not only the wide range in hardenability when the hardenability is dependent on one alloy, but also the relatively low overall hardenability when only one alloying element is present. Even though the theoretical hardenability of manganese is about the highest of the usual alloying elements, the hardenability of this alloy lies between those for carbon steels and the chromium-molybdenum steels. The addition of another alloy, such as molybdenum, increases the hardenability tremendously. The addition of a third alloy, such as chromium, increases the hardenability to such an extent as to make the alloy almost uncontrollable.

38. The average hardenabilities of the cast steels studied are given in

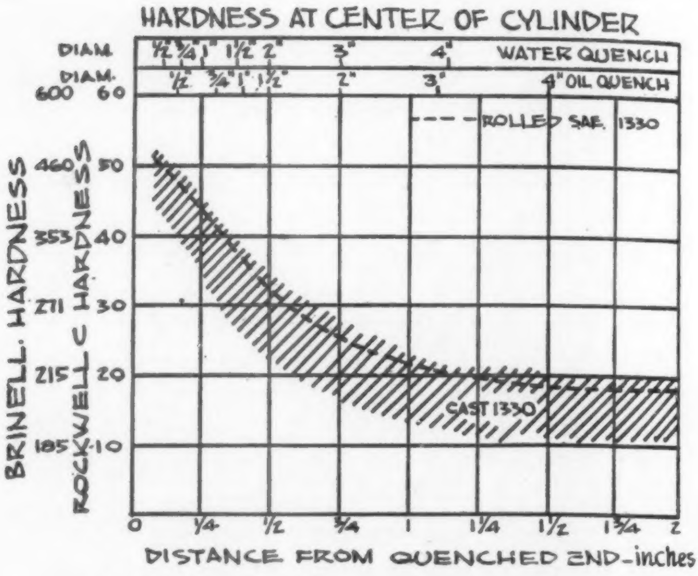


FIG. 8—HARDENABILITY OF MEDIUM MANGANESE CAST STEELS.

Figs. 9 and 10. The average hardenability, as determined by the end-quench method, and the hardness in the center of simple sections can be obtained from the charts. It should be emphasized that the curves are applicable only to fine-grained aluminum-killed cast steel, and to simple sections like a cylinder. Cooling rates at the base of gear teeth, for example, depend on the design of the gear and must be determined experimentally.

COMPARISON OF EXPERIMENTAL AND THEORETICAL HARDENABILITY

39. Field[6] has developed a correlation between the work of Grossmann[2] on the effect of grain size and composition and hardenability as determined by the end-quench test. Figure 11 shows the average end-quench hardenability curves as determined experimentally, and those calculated from the average chemical composition of the test specimens. As can be seen, there is a close agreement between the two. Most of the curves agree within one or two points Rockwell C hardness, well within the limits of experimental error. The greatest variation, 5 points Rockwell C hardness, is shown by the 4130 steel. The hardenability of this particular steel, as determined experimentally, is consistently 4 to 5 points Rockwell C hardness below that predicated by the analysis.

SUMMARY

40. The hardenability of 11 fine-grained, aluminum-killed cast steels has been determined by the end-quench method.

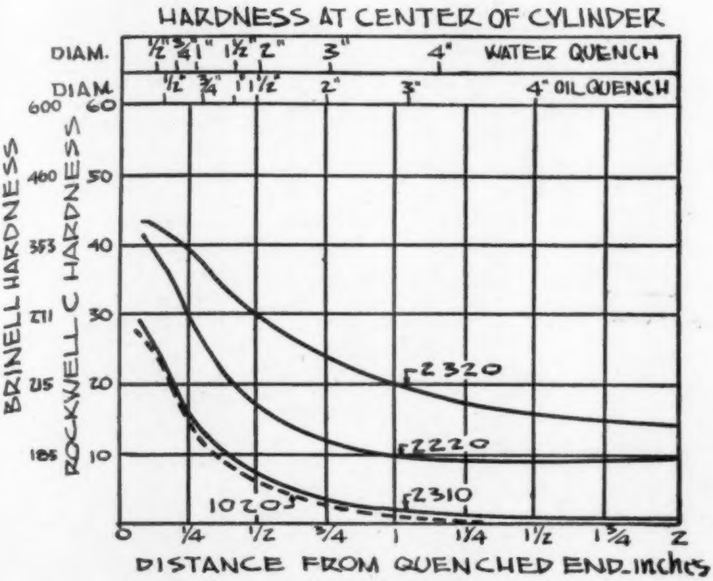


FIG. 9—AVERAGE HARDENABILITY OF CAST CARBURIZING STEELS.

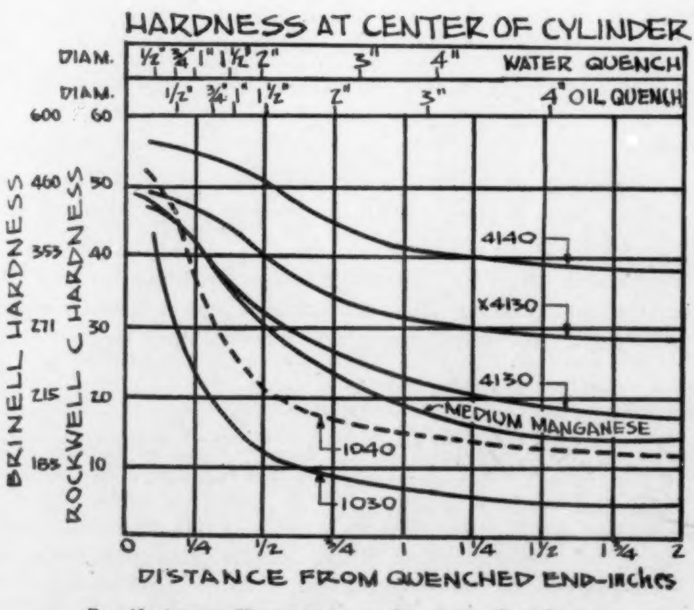


FIG. 10—AVERAGE HARDENABILITY OF STRUCTURAL CAST STEELS.

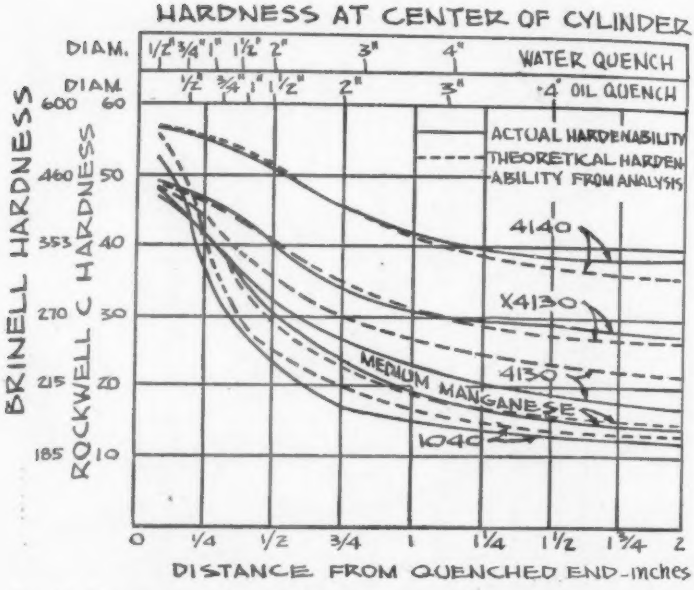


FIG. 11—COMPARISON OF ACTUAL WITH THEORETICAL (CALCULATED FROM AVERAGE CHEMICAL COMPOSITION) HARDENABILITIES OF VARIOUS CAST STEELS.

41. It has been shown that there is a significant difference between the experimentally determined hardenability curves of cast steel and those for hot-worked steel. This increase in hardenability results from the slightly higher silicon and metallic aluminum of cast steel.

42. The hardenability of cast steel can be calculated from the chemical composition and grain size, using the same formulae developed for hot-worked steel.

43. Examples are given showing the importance of controlling the hardenability, and the need of close control of chemical composition and grain size if the hardenability is to be controlled.

44. Suggestions are made regarding alloying practice for cast steel, not only from the standpoint of alloy conservation and cost, but also from the quality standpoint. Alloys are suggested to meet all three requirements.

REFERENCES

1. DAVENPORT, E. S., and BAIN, E. C., *"Transformation of Austenite at Constant Subcritical Temperatures,"* TRANSACTIONS, American Institute of Mining and Metallurgical Engineers, Iron and Steel Division, p. 117 (1930).

2. GROSSMANN, M. A., *"Hardenability Calculated from Chemical Composition,"* TRANSACTIONS, American Institute of Mining and Metallurgical Engineers, vol. 150, pp. 227-259 (1942).

3. CRAFTS, W., and LAMONT, J. L., *"The Effect of Silicon on Hardenability,"*

American Institute of Mining and Metallurgical Engineers, Technical Paper 1523, METALS TECHNOLOGY, Jan., 1943.

4. JOMINY, W. E., and BOEGEHOLD, A. I., *"A Hardenability Test for Carburizing Steels,"* TRANSACTIONS, American Society for Metals, vol. 26, p. 574 (1938).

5. SCOTT, H., *"Some Problems of Quenching Steel Cylinders,"* TRANSACTIONS, American Society for Metals, vol. 22, p. 68 (1934), and *"The Problem of Quenching Media for the Hardening of Steel,"* TRANSACTIONS, American Society for Metals, vol. 22, p. 577 (1934).

6. FIELD, J., *"Calculation of Jominy End Quench Curves from Analysis,"* METAL PROGRESS, pp. 402-405, Mar., 1943.

7. American Iron and Steel Institute, *"Contribution to the Metallurgy of Steel,"* no. 8 (1942).

DISCUSSION

Presiding: C. H. LORIG, Battelle Memorial Institute, Columbus, Ohio.

Co-Chairman: H. F. TAYLOR, Naval Research Lab., Anacostia Station, Washington, D. C.

CHAIRMAN LORIG: Mr. Caine brought out two very significant facts of interest to the foundryman. One is that it does not make much difference what the alloy content of the steel is; it is the carbon content that determines the maximum hardness that can be obtained. The other is that it is perhaps easier to control hardenability by using small amounts of several alloying elements rather than a large amount of a single element.

N. F. TISDALE[1]: How did you get hardenability of approximately 600 Brinell on 4140 wrought steel and 500 Brinell on cast steel?

MR. CAINE: The hardness values shown for 4140 steel must be correct, as McQuaid, Sykes, Jeffries, Grossman and a number of other investigators all have obtained 60 Rockwell C on fully hardened 0.40 per cent carbon steel, whether it be alloyed or not. The average hardness at the quenched end of the cast 4140 bars, as shown in Fig. 6, is 57 Rockwell C, within the limits of experimental error. The curve for rolled 4140 steel is that of the Iron and Steel Institute. One thing that I cannot explain is why the average hardenability curves for cast and wrought steels cross at a point ¼-in. to ½-in. from the quenched end.

MR. TISDALE: The carbon content of the steel has more bearing on the initial hardness than do the alloys present.

K. L. CLARK[2]: In any discussion of this sort, the limitations of the Jominy bar should be fully realized. That is, if we have an ideal quench at the end and the water spray on the end of the Jominy bar almost approaches an ideal quench, the heat transfer for the first ¼-in. is very rapid, and if we make a slight error in spacing, the hardness reading may be thrown off considerably for any given distance within the first ¼-in. Likewise, I would like to point out that beyond ¾-in., the Jominy bar does not give very reliable results, because the rate of heat transfer levels off beyond about ¾-in.

J. G. KURA[3]: You showed the hardenability of cast and wrought steel of the same grade with the cast steel having a higher hardenability than the wrought steel. Were these cast and wrought steels made from the same heat?

[1] Molybdenum Corp. of America, Pittsburgh, Pa.
[2] Naval Research Lab., Anacostia Station, Washington, D. C.
[3] Battelle Memorial Institute, Columbus, Ohio.

MR. CAINE: No, they were not made from the same heat.

MR. KURA: I believe that if cast and wrought were made from the same heat, most of the wrought material would have a higher hardenability than the cast material.

MR. CAINE: A fairly extensive work by Rowland* shows that the hardenability of cast and wrought specimens made from the same heat is exactly the same, within the limits of experimental error.

C. K. DONOHO[4]: We have done some work on the hardenability of cast steels, using a cast Jominy bar. The one-inch diameter test bar is cast in a metal mold about an inch longer than required, so that when cut to length there is a clean surface at the end to be quenched. We have found that hardenability, as determined with these specimens, correlates very closely with the analysis. On one or two occasions we were able, from the hardenability tests, to correct analytical errors. For instance, if we get 58 or 59 Rockwell C hardness near the end of a Jominy bar of 4140 steel, we know that the carbon content has to be about 0.43 per cent. When all elements present are considered, the Jominy curves generally relate very closely to the composition of the steel.

[4] American Cast Iron Pipe Co., Birmingham, Ala.

*METAL PROGRESS, p. 1133, December, 1943.

Better Quality Aluminum and Magnesium Castings for Aircraft

By Robert E. Ward*, Teterboro, N. J.

Abstract

In this paper, the author calls attention to the necessity of producing light metal aircraft castings of the quality and in the quantity demanded by the present emergency. Close coordination of the work of designers, engineers and foundrymen is given as the fundamental essential in high quality casting production. A number of fundamental principles of casting design, with which the designing engineer should be familiar, are listed in the paper.

Introduction

1. Although there are a large number of foundries now producing aluminum and magnesium castings for aircraft, the quality of work turned out varies to the extent that only a relatively small percentage of these foundries are capable of producing high quality, light metal aircraft castings of intricate design so often required to meet present-day applications.

2. In many instances, light metal castings are new to the foundryman who, prior to the war, may have been in the gray iron, cast steel or copper alloy casting field. Foundries have been in production with light metals for several years, and still are not producing a consistently high grade casting in quantities required to meet production schedules.

Radiographic Inspection

3. Radiographic inspection of castings permits the use of lower factors of safety to the designer, since he no longer is required to double or triple the strength of the casting to allow for internal defects which, without radiographic equipment, are not discernible in a non-destructive test.

4. To make full use of this inspection method and to save weight, which is the goal of all aircraft designers, it is necessary that they be assured that a consistently high quality casting can be delivered on time in sufficient quantities before they will reduce the sections in castings and rely on the foundries to produce castings which consistently will pass the x-ray requirements necessarily

---

*Eclipse-Pioneer Div., Bendix Aviation Corp.

Note: This paper was presented at an Aluminum and Magnesium Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 27, 1944.

incorporated. Many times, the design subjects the casting to considerable stresses. In such cases, there is no choice but to secure reputable vendors, who may be overcrowded, rather than chance vendors whose quality is inconsistent.

5. J. B. Johnson* has stated that there is an urgent need for suppliers of high quality, light metal castings. It is not the purpose of this paper to present a magic formula for curing light metal foundry problems, but to review the fundamentals which are so often overlooked. While all of the following points are probably well-known to every foundryman and designer, experience has shown that every foundry, in one way or another, has neglected one or more of these points. There should be no excuse for this negligence, since there is little disagreement among foundrymen that the fundamentals herein presented are not sound. However, if the basic foundry practice is not consistently good, a product of consistently good quality cannot be expected.

CASTING DESIGN

6. Since the ease of production, speed of production and cost of a casting is more or less proportional to the complexity of its design, the layout stage is the first consideration. It can not be assumed that the average design draftsman can be an expert foundryman. Furthermore, there is no reason that he be one in order to design castings, but it is imperative that he consult an experienced foundryman or patternmaker when the first rough sketches are made, so that castability can be incorporated into the design with equal consideration to performance.

7. So often, the first opportunity a foundryman is afforded to look over a casting is when the machine drawing or casting drawing is submitted for quotation. At this time, it usually is too late to make any drastic changes in the design which might be necessary to insure a readily castable piece. It is up to the foundryman to offer his services, and to do everything possible to spread an educational program, for it is not only to his advantage but to the customer's advantage as well, since suggested changes so often will reduce the cost of the part, improve ease of making sound castings or expedite its production.

8. When the condition arises, as it often does, that a design has not been reviewed by a foundryman until a request for a quotation is submitted, there is no reason why suggested improvements in design pertaining to castability should not be made at that time. This is so often overlooked, and, as a result, pattern equipment is made, pilot castings and often production lots produced, and then, because of the unsatisfactory nature of the casting, it becomes necessary to make design changes which naturally mean a change in pattern equipment and a serious production delay.

9. Following are several fundamental principles of casting design with which every design engineer should be familiar:

(1) Sections should be maintained as nearly uniform in thichness as

*Chief, Materials Laboratory, Army Air Forces, Wright Field, Dayton, Ohio.

possible, and changes in thickness should be gradual through use of the proper fillets or tapers. The heavier sections should be at the top of the casting in order to provide for directional solidification into the risers. Heavy sections below light sections are difficult to feed, and chilling may not always give satisfactory results.

(2) Fillets always should be indicated at intersections and must be large enough to prevent shrinkage cracks, but not so large as to cause heavy cross sections which may not be fed through the thinner walls.

(3) Castings should be made as simple as possible. It often is advisable to make two sections instead of one, for the sake of simplicity.

(4) Protruding parts, which may be damaged in shake-out of the mold or warped in heat treatment, should be avoided.

(5) Large cores which are difficult to support may shift in the mold, causing mis-runs or wall thicknesses less than allowable.

(6) Draft angles should be shown on machine drawings as well as casting drawings to prevent later interference with machining operations.

(7) Allowances for finish machining should be either indicated on individual surfaces or noted on the drawing, since this practice varies somewhat in the industry.

(8) Design for easy division of the pattern—straight parting lines are desirable and are essential if machine molding is to be done.

(9) As few cores as possible should be used, and these should be simple. Many foundries find the coreroom to be the "bottleneck," since present-day design requirements employ a large number of cores. Simple cores may be machine made, which is quicker and less expensive. Undercuts should be avoided, sufficient support allowed, pockets should be open to relieve core gases, and holes provided where necessary for removal of the core wires.

(10) Metal inserts should be avoided where possible, since these present a problem in sand castings, causing blow-holes if the inserts are not dried thoroughly and preheated.

(11) Avoid large areas of thin sections, since these are difficult to cast.

(12) Allow sufficient draft to permit easy withdrawal of patterns, and avoid undercuts to permit straight drawing of patterns.

(13) Pertinent information, such as pressure tightness, stressed sections and x-ray requirements should be incorporated in the drawing.

(14) Marking and lettering on the casting should be placed so that it will not interfere with drawing the pattern equipment or gating the casting.

(15) Machining pads should be cast on when necessary.

10. The foregoing are a few fundamentals. The exact tolerances, draft angles, section thicknesses, etc., depend to some degree on the particular design, and it is necessary, therefore, that the foundryman be consulted during the design stage so that maximum advantage can be taken of these points.

PRODUCTION SCHEDULES

11. The production forecast for the part should be established and obtained by the foundryman, especially if he is to make his own pattern equipment, so that the choice of metal or wood pattern equipment, machine or hand molding and other foundry procedures may be made correctly. All too often, a casting is placed into large production, using pattern equipment and molding methods which were designed for only a few parts, and progressing month-to-month with patched-up equipment, resulting in inferior quality castings.

Gates and Risers

12. When a design has been established, the gating and risering should be carefully calculated. Indiscriminate use of gates and risers is harmful and costly. It is good practice in gating design to establish the gates into the casting and work from there to the sprue or sprues. Areas should be calculated to insure that the cross-sectional area of the runners is equal to the area of the gates, and that the cross-sectional area of the gates is less than the cross-sectional area of the sprue or sprues at their narrowest point. This insures the proper choking at the sprues, and uniform, unrestricted flow through all portions of the casting. Castings should be fed as near the bottom as possible, and at as many places as is necessary to insure uniform metal temperature throughout any horizontal plane of the casting.

13. Gates and risers should be a part of the pattern equipment, and should not be cut by hand after the pattern has been drawn, for two reasons: (1) It is impossible to get the same type of gating and risering in each casting, and (2) cutting a gate or riser and smoothing the surface of the sand afterward changes the properties of the sand from those which are obtained when a pattern is drawn. Gates and runners should be of the same material as the rest of the pattern, and not of clay or some other molding material which will wear off rapidly and may be marred easily, leaving an irregular surface on the gate or runner.

14. Before production is started, pilot castings should be made from the production pattern equipment under conditions of close control, and such

factors as sand conditions and metal temperatures should be recorded, along with dimensional records and x-ray reports. Should regating be necessary, it should be of a temporary nature until satisfactory castings are obtained, but then should be made permanent and additional pilot castings run to check the permanent gating. If the x-ray examination is satisfactory, as indicated from a number of samples, the part is ready for production.

15. Once in production, the part must be made with the same type of sand, the same alloy, poured at the same temperature and under the same conditions. No changes of any sort from the procedure should be allowed. This is extremely important. Should it become necessary, for some reason or another, that the gating, risering or molding methods be changed, the castings then should revert to the experimental stage until the new methods have proved satisfactory.

16. In order to insure consistent quality after the casting has been put into production, it is necessary that every operation be controlled as strictly as possible in order to reduce to a minimum the many variables which are encountered in making castings. This is especially true of sand castings.

17. It is not only necessary to establish workable foundry procedures, but it is necessary to enforce them in every respect. First, each procedure should be put in writing, then distributed to all parties concerned and finally controlled to prevent departure from these procedures. Rule-of-thumb methods should be avoided wherever possible, and every effort be made to eliminate the variation of the human element.

18. Sand must be controlled at all times. Uniformity of the properties of the sand, from one batch to another and from one day to the next, is an absolute requisite. As many tests as are found necessary should be conducted to guarantee uniformity. There are instruments for making all the necessary tests, and these should be used. They are far more accurate than the judgment of even an experienced molder or foundryman.

Melting and Pouring

19. Melting and pouring must be standardized. The procedures for fluxing, superheating, refining and pouring must be controlled closely. Many bad castings occur as a result of gassy metal, dross inclusions, improper pouring temperatures and alloy contamination. Pouring temperatures must be held to those determined when pilot castings are made. This is just as important in a sand foundry as in a permanent mold or die casting plant, although the metal mold manufacturers usually are more careful in this respect.

20. Scrap gates and risers and other metal to be remelted must be sorted carefully and remelted with new metal in percentages that will not affect the physical properties of the final product. Melting must be definitely scheduled so that heats of metal do not remain at pouring temperatures for extended periods of time awaiting the molds which are to be filled. Cleanliness and

general all-around good housekeeping will aid in reducing the number of scrap castings.

Temperature Control

21. Heat-treating furnaces must be checked periodically to determine the accuracy of the temperature recording instruments, especially the solution-treatment furnaces, since these temperatures are very critical for light metal castings. All temperature recording instruments, such as thermocouples on melting furnaces and core-baking ovens, as well as the heat-treating furnaces, must be checked regularly to insure that they are indicating the correct temperature.

22. Control of the composition of the products of combustion of oil-and gas-fired melting furnaces not only increases pot life but reduces the likelihood of atmospheres which will gasify the molten metal. This is particularly true of aluminum alloys.

CONCLUSION

23. Making high quality aluminum and magnesium castings is not an art; it is a science and, as such, must be controlled in a scientific manner. There must be no guesswork. There must be a definite technical reason for every procedure in the foundry and, about all, there must be strict control. This point cannot be over-emphasized, since the science of metal casting is one involving many variables, any one of which may mean the difference between a satisfactory and an unsatisfactory casting.

24. It is known that excellent quality castings can be produced when the conditions are just right, and we know that there is a great need for this quality casting in aircraft today. In special cases, extreme care is taken in making sand castings and, as a result, their quality is superior to the average run of castings in the foundry. True, it is often more expensive to make high quality castings and, if the application does not warrant the best, it is then uneconomical to make use of a superior product. However, when a high quality casting is desired, a real effort should be made to produce a casting in production which the foundryman feels is as fine a casting as possibly can be made. This can be accomplished only by an earnest effort to study the casting thoroughly and control it in production.

25. The design engineers stand ready to make use of castings of consistently good quality for many more applications than are now employed. Many vital applications present themselves where the section thickness of the casting may be reduced, thereby saving a few oz. or a few lb. per casting and, perhaps, saving many lb. in a single airplane and increasing its load-carrying capacity proportionately.

26. It is up to each and every foundry supervisor to investigate thoroughly any procedures which give inconsistent results, analyze the problem, solve it

and then investigate the next one until he feels that the best standardized control is employed. There is no question but that improvements in standardization of control will yield a greater quantity of superior castings. They are needed now—now is the time to make more of them.

DISCUSSION

Presiding: L. BROWN, Magnesium Fabricators Div., Bohn Aluminum & Brass Corp., Adrian, Mich.

Co-Chairman: J. C. FOX, Doehler Die Casting Co., Toledo, Ohio.

D. BASCH[1]: It would be very hard to improve on Mr. Ward's excellent paper. How ever, there were a few points that are in line with his suggestions, but should be added. One of them is that the x-ray check of pre-production samples should be accompanied by a breakdown test, because x-ray examination is not by itself a means of determining the serviceability of a casting, but simply a control of the quality of a casting after maximum permissible structural deficiencies not interfering with serviceability have been established.

This breakdown test, which should be based on the engineering requirements as laid down by the engineer, serves another excellent purpose in that it prevents a rejection of the casting if failure is not due to faulty metal, faulty structure or faulty foundry practice, but to a mistake on the part of the designer, that is, if he has under-designed the casting. Many times we find it advisable, after we have run the breakdown and x-ray and made an analysis and everything of that sort, we go back to the designer and say, "You had better redesign the casting if you want it to stand the service that you expect from it."

Now in line with that it might be interesting to note that your Association has put in motion the machinery to establish specifications for these controlled high quality castings which are concurrent with the specifications for ordinary run castings but do not supersede them. Castings of this controlled quality should be used only where it is definitely necessary to have some casting that can be relied on under any emergency that service may provide, where the failure of the casting might mean the death of an operator, the failure to consummate an important military objective or anything of that sort. The consumers must realize that castings of that sort will naturally cut down the number of available producers, they will cost more and all that, and they should not be resorted to unless there is some very good reason for going to all that trouble.

G. ELLIS[2]: Have you used the fluorescent penetrant inspection?

MR. WARD: Yes, we use it, especially on die castings and permanent mold castings. We found the fluorescent method of inspection, or black light method, particularly useful in die casting and permanent mold casting inspection, where surface cracks are apt to be more prevalent than in sand castings. It must be used with care and the interpretation must be made with good judgment, since the inspection is extremely critical. However, one feature of this inspection is that if we have small castings that show cracks under this fluorescent light, if the casting is broken at this crack and then the

---

[1] General Electric Co., Schenectady, N. Y.

[2] Magnaflux Corp., Chicago, Ill.

cracks are examined again under the fluorescent light, it will show without any trouble at all the depth or penetration of the crack and indicate whether it is merely superficial or something that is serious.

C. E. NELSON[3]: It is quite important that people who use castings give considerable thought as to which castings and what parts of those castings must have high quality, and insist that the producers give them quality in those particular places. In many cases the quality demanded is unnecessarily high; in others, the quality specified is too low. If the foundry technicians responsible for the quality of a casting are properly advised as to the regions in a casting which are critical, they may then be able to concentrate on these areas and on critical castings, rather than spread themselves so thin trying to make all parts reach an unnecessarily high standard.

[3] Dow Chemical Co., Midland, Mich.

Introductory Observations on the Rate of Solidification of Malleable Iron

By B. C. Yearley, R. P. Schauss and P. A. Martin*, Cleveland, Ohio

Introduction

1. The problem of gating and feeding malleable iron has been such a complex one that a series of experiments have been performed to determine, if possible, a sound basis for considering the difficulties involved.

2. Feeding a malleable casting is, in the final analysis, a problem of supplying sufficient liquid metal to any section to compensate for a volume change. This volume change is brought about by the temperature drop before solidification and by the change from the liquid to the solid phase. This change in volume has been shown by various investigators to be approximately one per cent for each 100 degrees of temperature drop before solidification and 4 per cent during solidification. Therefore, it is necessary, if a solid casting is to be obtained, to supply by some means 5 per cent by volume of liquid metal to every section of a casting during solidification.

3. There are three principal methods by which liquid metal is or can be supplied to compensate for this volume change:

(1) Metal which solidifies during the filling of the mold cavity will automatically receive sufficient liquid metal to compensate for its volume change.

(2) One section of a casting may draw liquid metal from another section of the same casting if the rate of solidification of one section is more rapid than the rate of solidification of the other section.

(3) External reservoirs (feeders or heads) may be used, but the rate of solidification of these must be slower than that of the section which they are feeding.

4. In all three methods of supplying liquid metal to compensate for the volume change, the rate of solidification is an important factor. It seems possible that the feeding and gating problem can be approached by studying the rate of solidification. Possibly such a study will allow the predicting or control of what will occur when a casting freezes.

---

*National Malleable and Steel Castings Co.

Note: This paper was presented at a Solidification and Heat Transfer Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 25, 1944.

SOLIDIFICATION

5. The process of solidification is one of removing heat from the liquid metal. To predict how or when a casting will solidify is thus a question of being able to determine the heat transfer from the metal to the molding medium. This transfer of heat is undoubtedly affected by a great number of variables. Among them are:

(1) The conductivity of the molding medium.
(2) The specific heat of the molding medium.
(3) The temperature to which the mold is heated by the metal filling the mold.
(4) The design of the casting, such as re-entrant angles, sections which interfere with normal heat transfer, etc.
(5) The location of casting surfaces in relation to the outer mold surfaces.
(6) Internal coring.
(7) The location of feeders, gates and heads.

6. Thus, when the variables which affect heat transfer are considered, the amount of metal which will solidify during the time required to fill the mold cavity becomes a function of the following:

(1) Conductivity and specific heat of the molding medium.
(2) Temperature of the metal.
(3) Time.
(4) The amount of heat imparted to the mold by the liquid metal flowing over the mold surface.

Gates and Inlets

7. It seems probable, after considering the above factors, that the location of the gate or inlet for the metal should be studied from the angle of the effect of the metal flowing over the sand on the solidification rate of the particular section. An example of this is illustrated in Fig. 1.

8. This figure illustrates the fact that it is sometimes quite difficult to feed a heavy section when the casting is poured through this section. The

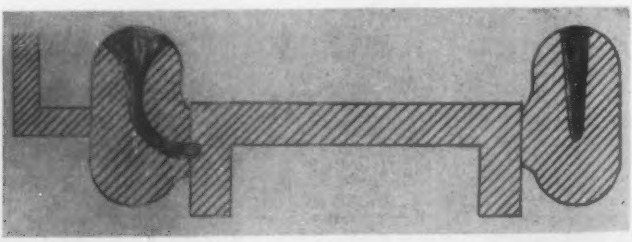


FIG. 1—METAL FLOWING THROUGH THE HEAVY SECTION AT LEFT HAS HEATED THE SAND, THUS REDUCING THE RATE OF HEAT DISSIPATION AND CAUSING THE SECTION TO REMAIN LIQUID LONGER THAN SECTION ON RIGHT.

difficulty is primarily due to the fact that the molding sand around the heavy section has been heated by the metal flowing over it. This heating of the mold cavity has retarded the solidification of the heavy section to such an extent that practically all the feeder was frozen before the casting solidified. Under these conditions, little or no solidification during the pouring time can be expected since the incoming metal will wash away any frozen particles. Thus the feeder will be forced to supply more metal to the casting than would be necessary had the heavy section partly solidified during pouring.

Casting Design

9. Similarly, when the factors which affect heat transfer are considered in studying casting design, it is apparent that one section of a casting may freeze faster than another, even though it may be of greater mass. Since it is a known fact that one section of a casting will draw metal from another, it is necessary in order to secure solidity to be able to predict which section will freeze first. Some of the variables which affect freezing rates can be explained as follows:

Re-entrant angles retard solidification because the molding sand in in the angle is heated quickly to a high temperature and dissipates the heat slowly. Air is a much better conductor of heat than is sand. Any part of the casting which is near the outer mold surface will lose heat more rapidly and thus solidify more quickly than will a similar section deep inside the mold.

Internal coring can retard solidification. The heat transmitted to an internal core often must travel a considerable distance through the sand before it can be dissipated. Since sand is such a poor conductor, this rate of dissipation is quite slow—much slower than is true in the case where the heat can reach the mold surface readily.

Feeders and Heads

10. The third method of supplying liquid metal to casting during solidification (feeders and heads) is also influenced by the various factors which affect heat transfer. The primary function of a feeder is to retain metal in the liquid form. To do this, a feeder should be placed, if at all convenient, in a position where its heat loss will be slower than that of the casting it is feeding. It is well to remember that even under good conditions, where the heat loss of feeder and casting is the same, a feeder supplying a 2-in. section will have at least a one-inch solid shell. All other things being equal, the loss of heat from any feeder is directly proportionate to its surface area. Thus a well designed feeder will have a high ratio of mass to surface area. Static pressure does not have much to do with feeding ability so that the height of a feeder is of little importance except for one factor, which will be discussed later.

11. Live feeders, i.e., feeders through which the casting is poured, have

a favorable freezing rate because they receive the last hot metal and because the sand surrounding the feeder has been heated by the metal flowing over it. On the other hand, dead feeders, i.e., those not connected to the sprue, have a high solidification rate in relation to the casting. In this case, the feeder has been filled by metal running through the casting and thus the metal is of a lower temperature. In addition, the feeder cavity has not been heated by the liquid metal as much as has the casting cavity.

12. Open feeders or heads, since they are exposed to the air and since they are also filled from the casting, have a very high freezing rate. The most efficient feeder, from the point of view of liquid metal available for feeding purposes, is the live feeder.

13. The feeder must be connected to the casting by a suitable mouth. When the factors affecting heat transfer are considered in the study of the design of the mouth of feeders some interesting facts are disclosed:

(1) The ratio of mass to surface area must be as high as possible. This suggests a round mouth rather than a flat one.

(2) The sand surrounding the mouth should be heated as much as possible during the pouring of the casting because a low rate of heat loss through the sand is desirable.

14. This suggests sharp re-entrant angles between the feeder and the casting. Surprisingly good feeding results have been obtained using the thin vertical mouths illustrated in Fig. 2.

Volume Change and Heat Loss

15. Connecting the process of solidification of a casting with the factors which affect the time of the volume change and the variables which control heat loss leads to some interesting deductions.

16. The freezing of the metal in a casting starts with the formation of a thin film or skin at all surfaces where the iron is in contact with the molding medium, as shown in Fig. 3. This film will vary in thickness with the rate

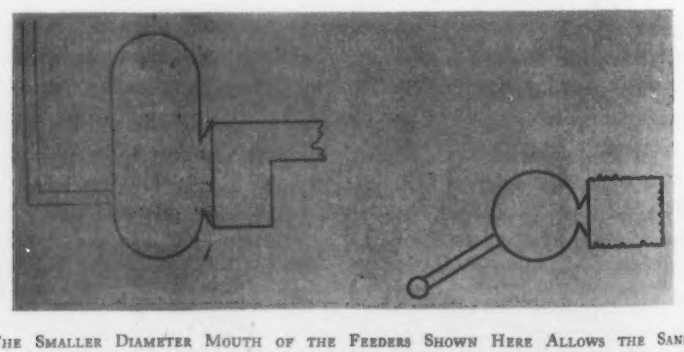


FIG. 2—THE SMALLER DIAMETER MOUTH OF THE FEEDERS SHOWN HERE ALLOWS THE SAND IN THE RE-ENTRANT ANGLES TO BECOME HEATED AND ALLOWS THE FEEDER TO PERFORM ITS FUNCTION OVER A LONGER PERIOD OF TIME.

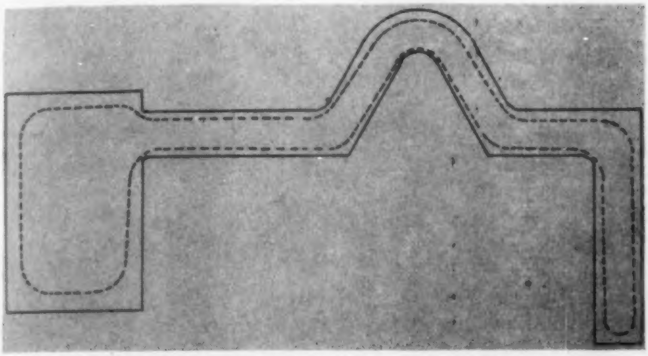


Fig. 3—Illustrating Skin Formation in Casting.

of heat transfer of the mold. It is thickest at corners where the metal projects into the sand, and thinnest at fillets where the sand projects into the metal. This skin becomes thicker as time is allowed for the transmission of heat into the mold. Under normal conditions, an air-tight envelope will be formed which contains the remaining liquid metal. As more and more solid metal is deposited on the inner side of this envelope, a partial vacuum will be formed due to the change in volume between the liquid and solid phases. This partial vacuum may rupture the outer skin and draw mold gases through it, thus forming a cavity.

17. Ruptures are most liable to occur at points of poor heat transfer, such as fillets or points where the sand projects into the metal. This accounts for the fact that surface indications of a shrink are most likely to occur at fillets and re-entrant angles. Unfed bosses will sometimes settle or draw down on the cope surface or at the junction of the boss and the casting, as shown in Fig. 4. Attempts have been made to allow for the settle on the cope surface by crowning the pattern at this point. This method usually is unsuccessful because as soon as the pattern is crowned enough to produce the mechanical strength of a dome, the boss will draw in on the drag side, as shown in Fig. 5.

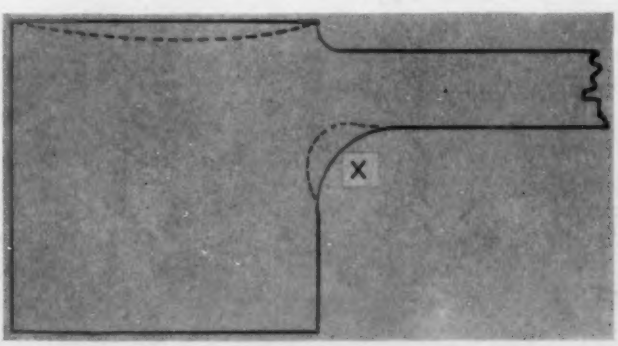


Fig. 4—Draw-Down on Cope Caused by Partial Vacuum.

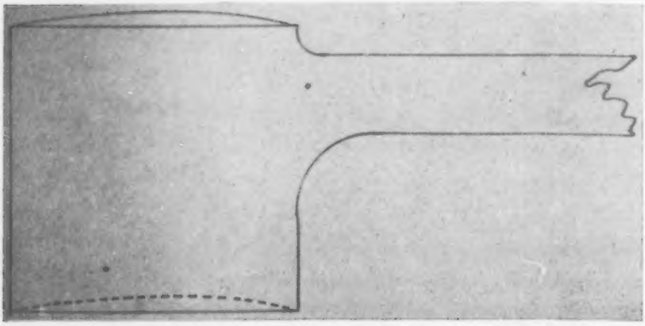


FIG. 5—CROWNING COPE TO PREVENT DRAW-DOWN OFTEN RESULTS IN THE DRAG SURFACE DRAWING IN.

This phenomena is certainly an indication of a negative pressure within the envelope of solid metal which forms the outside of the boss.

18. When such a condition exists, all that is needed to make this section solid is to have a connection to a supply of liquid metal and allow the boss to suck metal from this liquid reservoir. No static pressure is needed to force metal into the boss. A condition such as this is possible only when there is no break in the skin of the casting. Had the negative pressure developed before a strong envelope was formed at the point "X" in Fig. 4, mold gases would have been drawn into the casting, relieving the negative pressure and giving the characteristic shrink hole commonly seen at re-entrant angles.

Feeding Pressure

19. When it is possible to produce an air-tight skin around a casting feeder, height is of little importance. There are cases where it is necessary to use a feeder, higher than the casting, to produce an impervious envelope. The solidified skin of a casting is produced by the mold absorbing heat from the metal. If the metal is not in contact with the sand, the rate of heat absorption will be considerably decreased. The metal is held against the cope surface by the static head of either the sprue or feeder. If the feeder is lower than the casting and the sprue freezes first, there will be no pressure to hold the metal against the cope surface. Such a condition will result in a thin, easily broken film being formed on the cope surface. When this film ruptures, there will be no negative pressure to draw metal out of the feeder, and a shrink will result.

20. Whenever it is not possible to produce an air-tight envelope, feeders must be designed to exert static pressure, that is, be made higher than the casting. Another condition will require the use of feeders which exert static pressure. If the metal contains dissolved gases, which are evolved during solidification, these gases will relieve the negative pressure normally developed, and static pressure will be required to insure solidity.

21. Feeding or producing solidity in a casting is, in the final analysis, a

problem of timing the solidification of every part of the casting. To produce solidity, every section of a casting as it freezes must be supplied with liquid metal from some source. The source of this liquid metal may be, and often is, some part of the casting, but the last section or sections to freeze must be supplied by some external means.

Chills

22. One tool for the timing of freezing, which the foundryman has used for years, is the chill. This molding medium has a high specific heat and a high conductivity. These characteristics cause a much more rapid extraction of heat from the liquid metal and as a result a much higher rate of solidification. It is not possible to remove a shrink by using a chill, but it is possible, within certain limits, to time the freezing of a particular section so that it will draw liquid metal from another section. The last section to freeze can be then fed by a suitable feeder. As long as any section can be supplied with the proper amount of liquid metal to compensate for the change in volume as it freezes, no criticism of the use of chills is justifiable.

Solidification Tests

23. *Procedure:* In order to obtain definite information on the freezing characteristics of malleable iron as discussed in the introduction, it was decided to follow a program similar to that of E. C. Troy in his work on the solidification of cast steel.

24. *Equipment:* The equipment used consisted of the three patterns shown in Fig. 6. These patterns were 1½, 3 and 4 in. square by 8 in. in height. They were molded in the wooden flask of Fig. 7.

25. *Materials Used:* The malleable iron used in the tests came from a cupola-air-furnace duplex arrangement. The analysis of this iron was held within narrow limits of carbon, 2.45 to 2.60 per cent; silicon, 0.85 to 1.00 per cent; and manganese, 0.35 to 0.45 per cent. The iron was tapped into a covered ladle and then into the mold. Except for the tests to determine the

Fig. 6—Patterns Used in Tests.

FIG. 7—WOODEN FLASK AFTER PATTERN HAS BEEN WITHDRAWN.

effect of temperature upon solidification, the temperature of the iron was maintained between 2800 and 2850° F.

26. In order to lower the temperature of the iron for the tests for effect of temperature, iron was poured from the ladle into a 50-lb. hand ladle and held for varying lengths of time. The temperature was read on the iron in the hand ladle with the disappearing type filament optical pyrometer and the iron then was poured into the mold.

Sand

27. Solidification tests were made with sands having the properties shown in Table 1 and classified as follows:

An oil-sand core made of all sharp sand.
No. 1—A fine natural molding sand.
No. 2—A medium fine sand facing.
No. 3—A production system sand.
No. 4—A special sand produced by adding more sea coal to sand No. 3.

28. Chills ¼, ½ and ¾ in. thick by 3 by 8 in. were used in conducting the chill tests. These chills were first brushed with a thin coating of shellac and then dusted lightly with a thin layer of dry sand. The prepared chills were dried at a low temperature before using.

Test Method

29. Molds were made with one of the patterns shown in Fig. 6. The top core was set in place and the mold was moved to the pouring station. The mold was filled as shown in Fig. 8, and the stop-watch was started at the moment that filling had been completed. The mold was transferred to the supports of Fig. 9 and, as soon as the proper time had elapsed, it was up-ended

Table 1

TEST DATA ON SANDS USED IN SOLIDIFICATION TEST

Properties	Sand *No. 1*	*No. 2*	*No. 3*	*No. 4*
Moisture, per cent	7.0	4.2	3.0	4.4
Permeability	20	40	80	50
Green Compression Strength, psi.	5.5	7.5	5.7	8.0
Carbon, per cent	0.0	4.5	2.4	6.5
Screen Analysis				
Remaining on Screen, per cent				
20	0.8	0.5	0.3	0.3
40	1.6	10.3	18.8	18.8
50	1.4	7.8	14.2	14.2
70	3.0	10.2	17.4	17.4
100	5.4	16.3	27.3	27.3
140	24.2	17.5	10.8	10.8
200	33.8	18.2	2.6	2.6
270	14.8	8.2	1.5	1.5
Pan	9.4	5.0	0.8	0.8
Clay	5.6	6.0	6.3	6.3

as shown in Fig. 10. All of the remaining molten iron was allowed to run out, after which the casting was shaken out and set aside for measuring. The measuring was done with an indicating caliper measuring in sixty-fourths of an inch. Measurements were taken on all four walls of the specimen and at three places on the height of each of the walls. Care was taken to stay away

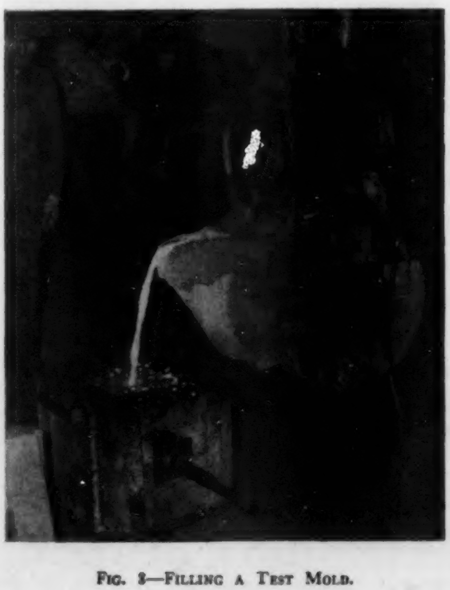


FIG. 8—FILLING A TEST MOLD.

FIG. 9—MOLD SUPPORTS USED IN EXPERIMENTS.

from the bottom of the specimen to eliminate the end effect from consideration. The average of all of the readings was made and was expressed in decimal equivalents of an inch. In all cases, the results shown were averages of two individual tests poured at least one day apart and measured at different times.

30. The chill tests were conducted by placing the chill on one side of the pattern and molding in the usual manner. The measuring of these specimens was done only on the chilled wall and on the wall opposite to the chill.

FIG. 10—UP-ENDING A TEST MOLD.

31. All of the molds were made by the same molder and all tests were conducted under the supervision of one man.

32. The results of the experimental procedure are plotted in the graphs, shown in Figs. 11, 12, 14, 15 and 16. These graphs represent, to the best of the authors' ability, the trends which were demonstrated by the test blocks. Considerable further work must be done to establish the exact position of the lines shown.

SOLIDIFICATION RATES

33. Figures 11 and 12 show the effect of common molding mediums on the rate of freezing of 1½ and 3-in. square blocks. It was found that a considerable length of time was required to form any measurable skin of metal on the mold surface. This is illustrated in Fig. 13 which is a picture of the test obtained on a 1½-in. block, with a solidification time of 10 sec. Only the four corners of the test block froze, which fact demonstrates the higher heat transfer rate at points where the metal projects into the sand. The principal difference between the curves for the 1½ and 3-in. test blocks lies in the time required to form the first measurable metal skin on the mold surface.

34. The 3-in. block required considerably more time to form a measurable skin. If this phenomena is taken into consideration and the curve for the 3-in. block compensated for this difference, it is found that the rate of skin forma-

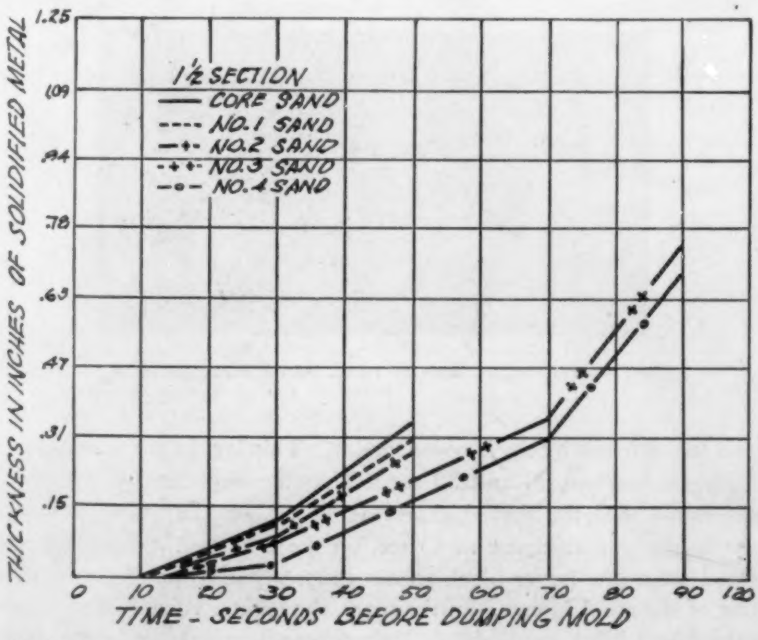


FIG. 11—RATE OF SOLIDIFICATION OF 1½-IN. SQUARE BLOCK IN SANDS SHOWN IN TABLE 1.

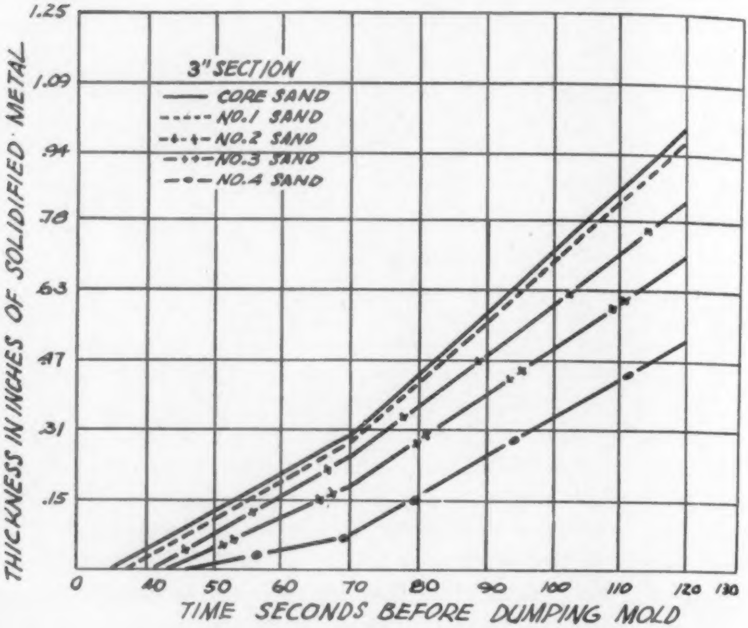


FIG. 12—SAME AS FIG. 11 BUT WITH 3-IN. SECTION.

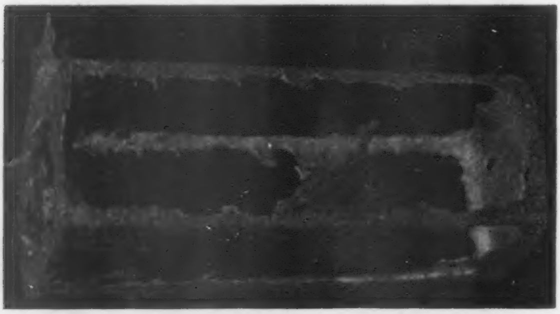


FIG. 13—METAL SOLIDIFICATION IN 1½-IN. SQUARE BLOCK AFTER 10 SEC.

tion on the two test blocks is quite similar. This lag, in the case of the 3-in. specimen, is between 20 and 30 sec. Thus a comparison of 1½ and 3-in. graphs shows that the skin thickness at 40 sec. on the 1½-in. test is quite similar to the skin thickness at 65 sec. on the 3-in. test. Such a lag is to be expected, since the larger block requires more time to pour with a resulting heating of the mold surface. Furthermore, the greater volume of metal poured into the larger block establishes a higher mean temperature in the specimen.

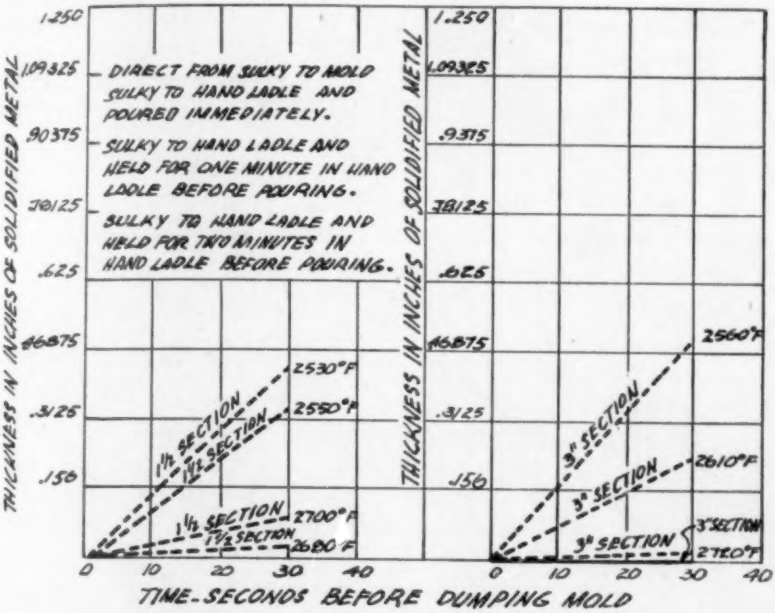


FIG. 14—EFFECT OF POURING TEMPERATURES ON FREEZING RATE.

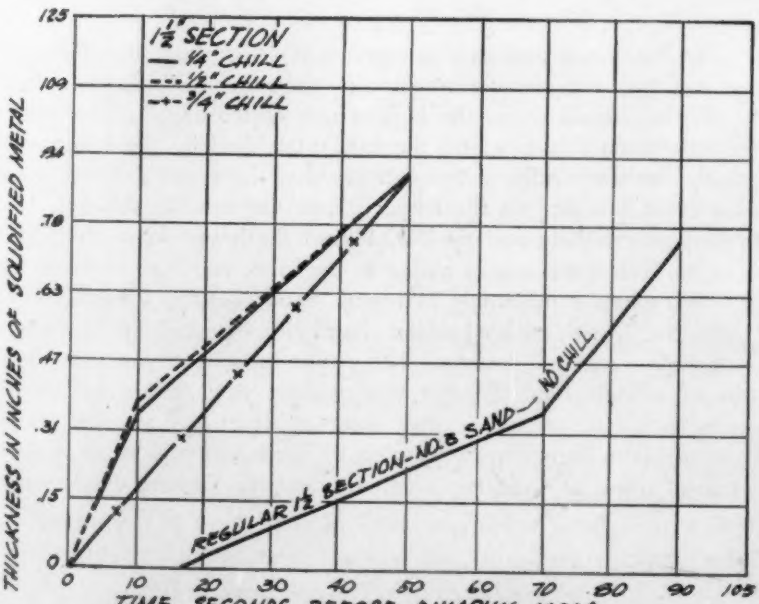


FIG. 15—DIFFERENCE IN SOLIDIFICATION RATE WHEN METAL IS CAST AGAINST A CHILL. SECTION, 1½ IN.

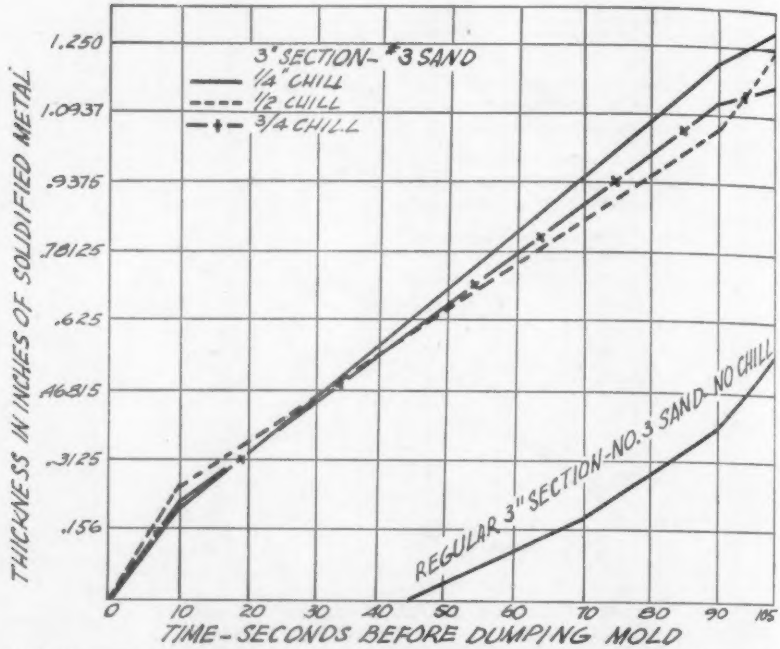


FIG. 16—DIFFERENCE IN SOLIDIFICATION RATE WHEN METAL IS CAST AGAINST A CHILL. SECTION, 3 IN.

Effect of Molding Sand on Solidification Rate

35. The four sands used in this experiment demonstrate that the molding medium can exert considerable influence on the rate of solidification. In both graphs, the core mold shows the highest rate of freezing, but there is little difference between this rate and the rate established by the finest molding sand used. Such a condition demonstrates that the permeability of the raw sand has little influence on the freezing rate, the core, in this case, having the highest permeability and the No. 1 sand the lowest permeability of the entire series. When sea coal is added to the sand, another variable is introduced which exerts considerable influence. Sand No. 2 is a mixture of sand No. 1 and No. 3, with sea coal added. Sand No. 4 is sand No. 3 with a considerably higher sea coal content. These tests indicate that sea coal retards the rate of solidification. Possibly this explains why surface indications of shrinks in re-entrant angles are often observed when high sea coal sands are used. If the skin formation is retarded by such a condition, there is more likelihood of the skin rupturing when the negative pressure develops during freezing.

Effect of Sea Coal on Solidification Rate

36. The influence of sea coal on freezing rate can be explained by considering its effect on heat transfer. Sea coal is used as a constituent of molding

sand to prevent penetration of the metal into the mold surface. There are two commonly accepted theories concerning the action of sea coal in preventing penetration. One theory contends that the gas evolved by the coal when heated to a high temperature serves as a cushion or blanket and prevents the metal from coming in contact with the sand. The other theory contends that the tar, which is distilled from the coal at elevated temperatures, fills the voids between the sand grains and thus prevents penetration. Either of these phenomena could produce conditions which would insulate the metal from the sand and thus reduce the rate of heat flow between the metal and the mold surface.

Effect of Pouring Temperature on Solidification Rate

37. Figure 14 illustrates the effect of the pouring temperature on the freezing rate. The freezing rate increases to a surprising extent as the pouring temperature drops. Furthermore, the lag between the 1½ and 3-in. specimen completely disappears at the lower temperatures. Both of these results are to be expected in view of the factors which affect heat transfer. The ability of the mold surface to absorb heat rapidly is very limited, due to the low heat capacity and poor conductivity of molding sand.

38. After the mold face has been heated to a high temperature, heat is absorbed more slowly since the temperature difference between the metal and the sand is less, and since the heat must be carried away from the mold face by conduction between the sand grains. If this early heat capacity is exhausted by reducing the temperature of superheat of the metal, the freezing rate will be reduced. The mold must absorb the latent heat of fusion of the iron in order that freezing may progress. Much more rapid freezing will result if the early heat capacity of the sand is used to absorb latent heat of fusion rather than temperature of superheat. The results illustrated in this graph (Fig. 14) demonstrate that the freezing rate can be greatly influenced by the temperature to which the mold is heated before the metal starts to solidify.

Effects of Chills on Solidification Rate

39. Figures 15 and 16 illustrate the rate of solidification when the metal is cast against a chill of various thickness. Here the lag between the 1½ and 3-in. blocks persists. In the case of the 3-in. specimen, there is practically no difference between the freezing rate produced by the different chill thicknesses. The graph for the 1½-in. block shows a slower freezing rate for the heavier chill. The authors have no explanation for this peculiarity other than the possible presence of some variable which was not detected.

40. Figures 17 and 18 illustrate the difference in metal wall produced on the test blocks by chilling one face. The graphs demonstrate that by the use of chills it is possible to solidify a heavy section before an adjoining lighter section will freeze.

FIG. 17—EFFECT OF CHILLS ON AMOUNT OF METAL SOLIDIFIED AFTER GIVEN TIME HAS ELAPSED.

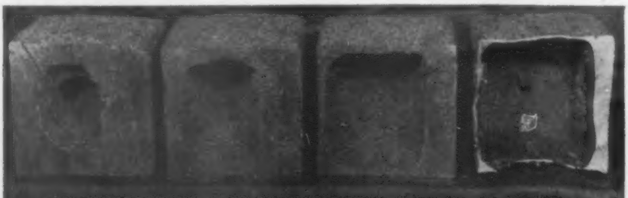


FIG. 18—EFFECTS OF VARIOUS DEGREES OF CHILLING ON SOLIDIFICATION OF MALLEABLE IRON.

CONCLUSION

41. The results noted in this paper are from the first of a series of experiments which must be performed to determine the freezing rate of malleable iron. When the freezing rate has been accurately determined, it should be possible to predict how any section of a casting may be fed.

DISCUSSION

Presiding: E. C. TROY, Dodge Steel Co., Philadelphia, Pa.

CHAIRMAN TROY: Most of us have been too prone to accept solidification in the mold as a proposition of the devil, and have been depending on prayer or the symbols of witchcraft to deliver us from the evil which seems to inhabit both the metal and the mold.

About 5 yr. ago at our plant, we ran into variables in practice that indicated it would be worthwhile to make some rough checks on the rates of solidification of the metal against sands of different types, metal mold faces, such as chills, and insulation materials. We did run quite a few tests. They were crude in every respect and it took us something like 3 yr. to get enough data together to be useful.

Quoting from a paper presented to the Steel Founders' Society some 2 yr. ago, in which I tried to sum up the reasons for obtaining this kind of information:

"One of the most important and least discussed functions of a molding material is its ability to remove heat from the liquid steel cast against its surface. It is obvious that the metal solidifies by loss of heat to the mold. There is much to learn about controlled solidification of steel. A great deal has been said and written about proper metal and mold temperature gradients for the promotion of proper direction of solidification. It should be kept in mind that while the desired object is controlled solidification, such solidification is producible only by controlling the rate of heat transfer from metal to mold.

"The production of metal temperature gradients in the mold results from transfer of some of the heat, of part of the metal, to portions of the mold and thus automatically establishes mold temperature gradients. The intensity of such gradients is influenced by original ladle temperature, number and locations of gates and rate of pouring through such gates. When mold temperature gradients are produced the direction and rate of solidification are established, providing that mold temperature gradients result in heat extraction gradients. Such is generally the case. Controlled gradient heat extraction, necessary to control of direction of solidification, can be produced by preheating sections of a mold, with a torch or with liquid metal steel during pouring, prior to completion of pouring or by making up the mold with materials having different heat extraction rates. Having a choice of different molding materials with a knowledge of their heat extracting rates would make possible great improvements in control of solidification. At present there are few materials used, but it would be well to have a greater knowledge of the relative heat absorption rates and capacities of these few."

D. P. FORBES[1]: In any of these tests that have been conducted so far, was there any evidence that a thin film of solidified metal would form which would afterwards be re-melted as the sand adjacent to the casting became heated above the melting point of the metal?

MR. YEARLEY: I can only answer that by observation rather than by actual results. We have every reason to believe that there are cases in which the film first forms and then later is re-melted and washed away.

K. A. DE LONGE[2]: In Fig. 15, where you show a thinner wall for the heavier chill, is it possible that the difference might be due to the amount of fine sand that is dusted on the shellacked surface?

MR. YEARLEY: That is quite possible.

MR. DE LONGE: Have you done anything as yet to check the effect of different moisture contents on the relative solidification rates?

MR. YEARLEY: We did not have time to carry on any experiments with regard to moisture contents. The sands used have quite variable moisture contents, all the way from no moisture, in the case of core sand, to a 7 per cent moisture content in the case

[1] Gunite Foundries Corp., Rockford, Ill.

[2] International Nickel Co., Inc., New York, N. Y.

of the finest sand. An interesting thing that was developed in that connection is that the rates of solidification for the sand with no moisture and for the sand with the highest moisture content are practically identical, which, to us, indicated that the moisture did not play as large a part as we had thought it might. There were some 300 or 400 test blocks made.

MEMBER: Were those sands of different grain size?

MR. YEARLEY: Yes.

CHAIRMAN TROY: We did check that in steel, and found that the grain size of sand had no appreciable effect on the solidification rate. I suspect that the same thing would apply in malleable, but I am not sure.

O. J. MYERS[3]: Has any work been done on the rate of solidification of castings in a zircon core sand? Some foundries use this material for a chilling effect.

CHAIRMAN TROY: Yes. We found that the rate of solidification on zircon sand is the same as that of a silica sand. There is a difference, but it is not found on a flat surface or a continuous surface. It is found only where heat storage capacity is of importance.

MEMBER: Why was the rate of solidification higher in the dry sand than in the green sand?

CHAIRMAN TROY: You will note that the difference between the solidification rates in the green sand and the dry sand was very small, except where sea coal was present. The dry sand core is a more dense core, and the slight differences mentioned in the paper might be due to the property of density.

Mr. Yearley, what material was used for chilling?

MR. YEARLEY: The same material as was poured against the chills, hard iron against hard iron.

[3] Wright Aeronautical Corp., Lockland, Ohio

The Effect of Copper in Some NE and Low-Alloy Cast Steels

C. T. Greenidge*, M. C. Udy*, and K. Grube*, Columbus, Ohio

Abstract

Copper was added to three low-alloy, 0.30 per cent carbon, cast steels in amounts up to 0.50 per cent and to a fourth steel in amounts up to 1.35 per cent. The first three steels corresponded to NE 8630 and 9430 grades and to a manganese-molybdenum type, while the fourth approximated an NE 8700 composition. The steels were tested for hardenability by the end-quench method and for tensile properties and hardness after water-quenching or normalizing, followed by tempering. Low temperature notched bar toughness was determined on specimens similarly heat treated. Copper had no effect on the temperature required to draw to a specified hardness. Hardenability was mildly increased by copper; the increase resulting from 0.50 per cent, probably being no greater than would be experienced from a normal variation in the other alloying elements. A moderate increase in as-normalized hardness was induced by copper; the effect being largely removed by tempering at 1000° F., or above. When present in amounts above 1 per cent, copper increased the strength and reduced the ductility of normalized steels; and normalized steels, drawn in the precipitation-hardening temperature range, or quenched and tempered in this range, showed the customary effects of precipitation-hardening. No precipitation-hardening was noted with copper up to 0.53 per cent. Room temperature tensile and notched bar properties of water-quenched and drawn steels were not affected by copper in percentages up to 0.50 per cent. This applies as well to toughness measured at —60° F.

Introduction

1. The NE (National Emergency) steels in the 8600 and the 9400 series are characterized by the presence of most of the common alloying elements in moderate amounts. Thus, the 8600 series, though classed as a nickel-chromium-molybdenum type, contains an appreciable amount of manganese, while the 9400 series, besides the elements in the 8600 series, also contains a notable

*Metallurgist, Battelle Memorial Institute.

Note: This paper was presented at a Hardenability and Heat Treatment of Steel Castings Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 27, 1944.

percentage of silicon. The range of these elements for the two types is shown below:

NE Type	*Mn*	*Si*	*Cr*	*Ni*	*Mo*
8600	.70-1.00	.20-.35	.40-.60	.40-.70	.15-.25
9400	.80-1.50	.40-.60	.20-.40	.20-.50	.08-.15

2. Development of these steels represents an intelligent solution to the problem of utilization of residual alloying elements in the scrap. With a specification requiring all these elements, the steel maker not only has a means of adjusting his composition to compensate for the residuals in his scrap, but by so doing, the "contaminants," themselves, are utilized and made an integral part of the steel composition.

3. Besides the alloys already mentioned, copper may occur in sufficient quantity in scrap to draw attention to its presence. Copper, like nickel, is one of those elements that is not oxidized in the melting process and accumulates as a residual in the steel. As in the case of the other alloys, it is important from a conservation standpoint to know what effects are attributable to copper and how it can be utilized to the greatest advantage. In formulating the NE analyses, no account was taken of the role of copper which is present in practically all scrap in amounts of 0.03 to 0.50 per cent and over; furthermore, no information on this score appears to be available. For this reason, an investigation of copper in one low-alloy and three NE cast steels was undertaken.

4. The steels investigated were NE 8630 and 9430 grades, a manganese-molybdenum steel, and a fourth type corresponding to the NE 8720 composition, except for having 10 points more carbon. Copper was added to the first three steels in amounts up to 0.50 per cent and to the fourth, up to 1.35 per cent.

5. Hardenability of the steels was determined by the end quench method, and tensile properties and hardness were obtained after quenching and drawing, and normalizing and drawing. In addition, the effect of copper on low temperature notched bar toughness was investigated.

EXPERIMENTAL WORK

Steel Processing

6. The steels were melted in a 300-pound induction furnace having a basic lining. The heats with low copper were made from ingot iron, and those with higher copper content from a low carbon steel scrap containing 0.20 per cent residual copper. The steels in the NE 8630 and 9430 group, and the manganese-molybdenum type were deoxidized with 0.10 per cent aluminum added to the bath about one minute before pouring, while the remaining heats were deoxidized with silicon. These distinctions in deoxidization practice are indicated in Table 1, which gives the composition of the heats used in the investigation.

Table 1

COMPOSITION OF EXPERIMENTAL LOW-ALLOY STEELS

Heat No.	*Elements, Per Cent*									*Al Deoxidation*
	C	*Mn*	*Si*	*P*	*S*	*Ni*	*Cr*	*Mo*	*Cu*	
				Plain Carbon (Grade B)						
8023	0.26	0.78	0.31	0.03	0.03	....	....	....	0.02	No
				NE 9430						
9567	0.30	1.04	0.50	0.025	0.024	0.32	0.32	0.12	0.06	Yes
9568	0.30	1.06	0.56	0.013	0.025	0.30	0.26	0.11	0.13	"
9569	0.31	1.02	0.46	0.012	0.025	0.31	0.29	0.11	0.30	"
9570	0.30	1.04	0.52	0.024	0.025	0.33	0.30	0.11	0.53	"
				NE 8630						
9547	0.30	0.82	0.34	0.027	0.022	0.48	0.55	0.19	0.08	"
9549	0.29	0.76	0.33	0.029	0.022	0.50	0.52	0.20	0.13	"
9548	0.31	0.89	0.38	0.032	0.025	0.52	0.57	0.19	0.32	"
9550	0.30	0.85	0.38	0.015	0.025	0.48	0.50	0.20	0.47	"
				*NE 8700**						
8143	0.27	0.77	0.33	0.03	0.03	0.52	0.56	0.27	0.05	No
8019	0.32	0.63	0.41	0.03	0.02	0.52	0.54	0.26	0.10	"
8024	0.28	0.82	0.34	0.03	0.03	0.52	0.53	0.25	0.46	"
8022	0.29	0.76	0.35	0.03	0.03	0.53	0.53	0.26	1.01	"
8036	0.29	0.82	0.34	0.03	0.03	0.52	0.53	0.25	1.35	"
				Mn - Mo						
9564	0.30	1.49	0.37	0.014	0.022	....	....	0.35	0.08	Yes
9565	0.33	1.67	0.35	0.019	0.025	....	....	0.34	0.16	"
9551	0.30	1.57	0.37	0.018	0.025	....	....	0.34	0.26	"
9566	0.28	1.61	0.35	0.024	0.022	....	....	0.34	0.53	"

*The chosen carbon range is not covered by the NE 8700 type; otherwise, the steel meets NE 8700 specifications.

7. Each heat was poured directly from the furnace into four standard 15-inch long, double-legged keel block molds of baked core sand. All keel block legs were given a homogenization heat treatment prior to machining into test specimens. A 6-hour holding at 1800° F. was given to the plain carbon comparison steel and the alloy steels of the NE 8700 type; whereas the other steels received a treatment of 12 hours at 1950° F. A heat treatment of 12 hours at 400° F. for hydrogen release was given to the specimens after the quenching and drawing treatments, but before final machining.

Brinell Hardness of Tempered Steels After Water Quenching or Normalizing

8. Following the homogenization heat treatment at 1950° F., hardness test specimens from the NE 8630 and 9430 and the manganese-molybdenum groups of steels were heated for one hour at about 100° F. above the critical temperature and water quenched. They were immediately transferred to a draw furnace at 400° F. to avoid quench cracks. Separate samples were then tempered at temperatures of 950, 1000, 1050, 1150, 1200, and 1250° F. for two hours

Table 2

BRINELL HARDNESSES OF COPPER-BEARING CAST STEELS DRAWN AT VARIOUS TEMPERATURES

Heat No.	*Per Cent Cu*	*Prior Treat-ment*	*Tempering Temperature, ° F.* 400	950	1000	1050	1150	1200	1250
			Brinell Hardnesses						
			NE 9430						
9567	0.06	W. Q.	444	298	283	262	248	235	217
		Normalize	209	207	201	187	198	192	195
9568	0.13	W. Q.	451	302	290	265	248	141	223
		Normalize	215	217	217	197	208	197	191
9569	0.30	W. Q.	457	302	293	268	255	235	229
		Normalize	223	214	212	198	202	198	198
9570	0.53	W. Q.	461	311	293	268	256	241	229
		Normalize	225	225	221	207	210	203	204
			NE 8630						
9547	0.08	W. Q.	...	321	302	272	262	244	235
		Normalize	229	217	217	197	208	198	197
9549	0.13	W. Q.	457	321	307	293	257	255	231
		Normalize	219	223	215	197	201	197	...
9548	0.32	W. Q.	467	325	317	285	269	255	240
		Normalize	257	248	241	229	228	221	210
9550	0.47	W. Q.	454	331	317	293	272	255	241
		Normalize	255	244	241	212	218	215	207
			Mn - Mo						
9564	0.08	W. Q.	457	326	321	302	262	241	229
		Normalize	241	237	235	221	219	215	203
9565	0.16	W. Q.	457	335	321	293	269	244	228
		Normalize	255	242	241	217	225	210	211
9551	0.26	W. Q.	454	337	321	306	269	248	235
		Normalize	262	255	252	212	229	217	216
9566	0.53	W. Q.	454	331	319	311	274	248	231
		Normalize	255	246	246	217	229	217	207

to obtain draw-temperature hardness relationships for these steels. The results of these tests are given in Table 2.

9. It is obvious from these data that copper has had no influence on the draw temperature required to obtain a specified hardness in the water-quenched samples. None of the steels bearing 0.50 per cent copper are more than 10 points Brinell higher than the low copper steels of the same series. Furthermore, the three groups also behave alike, each losing hardness at about the same rate. This information suggests that when copper is present in amounts up to 0.50 per cent it will not modify the usual tempering practice used on water-quenched, low-alloy cast steels to reach a certain hardness level.

10. In the case of normalizing prior to tempering, copper does have a mild influence on the hardness, the higher copper steels being as much as 25 points Brinell harder after the 400° F. draw than the low copper comparison steel. This effect, no doubt, is dependent on the hardenability of the steels, as the

hardnesses of the normalized specimens from the three base analyses are also dissimilar. These characteristics are illustrated in Fig. 1 where the spread in hardness between the high and low copper steel of each series is indicated by a band. The normalized manganese-molybdenum steels and NE 8630 type have a somewhat higher hardness level than the 9430 series. This difference is in agreement with their hardenability rating. (See Figs. 3 to 6.) Beyond a tempering temperature of 1000° F. the steels rapidly approach the same hardness, and at 1200° F. they all have about the same Brinell value.

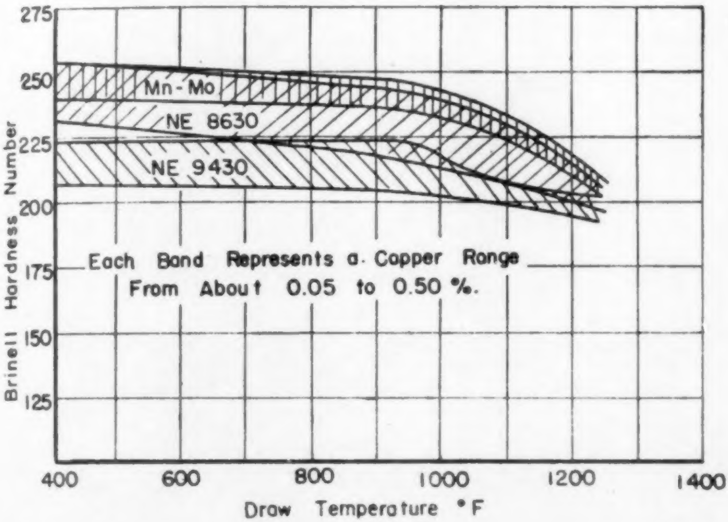


FIG. 1—EFFECT OF COPPER ON THE HARDNESS OF NORMALIZED AND DRAWN LOW ALLOY CAST STEELS.

Tensile Properties of Water-Quenched and Drawn Steels

11. Using the foregoing hardness-tempering temperature relationships as a basis, duplicate standard tensile specimens from the three types of steels were water-quenched and tempered to two hardness levels, namely, 230 to 250, and 300 to 320 Brinell. The tensile properties of the heat treated bars are set forth in Table 3.

12. The results of these tests agree with those by Patton[1], and Janitzky and Baeyertz[2], on rolled steels, which indicated that no significant difference in strength or ductility exists between any low-alloy steels if they have been fully quenched and tempered to the same hardness. While no summarized information has been published on cast steels of the NE grade to show the normal expectancy of properties, sufficient data are available on somewhat similar steels to indicate roughly what properties one might anticipate from the various NE compositions. Comparison of the NE 8630 and 9430 cast steels with a

[1]Numbers refer to the bibliography at the end of this paper.

Table 3

TENSILE PROPERTIES OF WATER QUENCHED AND TEMPERED COPPER-BEARING, LOW-ALLOY STEELS

Heat No.	Per Cent Cu	Quench Temp. °F.	BHN	Yield Strength 1000 psi. 0.1% Offset	Yield Strength 1000 psi. 0.2% Offset	Tensile Strength, 1000 psi.	Reduction of Area, Per Cent	Elong. in 2 in., Per Cent
				NE 9430				
9567	0.06	1550	245	90.0	88.7	112.6	46.0	19.7
9568	0.13		250	93.2	91.1	115.4	46.0	20.0
9569	0.30		250	93.1	93.3	113.6	46.0	21.2
9570	0.53		244	96.1	96.2	116.0	48.5	21.5
				NE 8630				
9547	0.08	1570	242	93.9	94.6	115.7	54.5	21.7
9549	0.13		232	88.7	89.1	110.5	52.5	21.0
9550	0.47		235	89.0	89.0	112.0	49.5	22.0
				Mn - Mo				
9564	0.08	1550	237	95.5	104.0	112.6	52.0	21.5
9565	0.16		252	99.8	99.9	116.4	47.0	19.5
9551	0.26		241	105.9	105.6	121.0	51.0	22.0
9566	0.53		252	99.5	99.6	116.1	46.0	19.5
				NE 9430				
9567	0.06	1550	319	123.0	128.0	144.5	27.5	10.5
9568	0.13		313	125.0	133.5	147.6	34.5	11.7
9569	0.30		317	130.0	132.7	146.9	29.5	10.2
9570	0.53		319	137.1	140.2	155.1	29.5	11.5
				NE 8630				
9547	0.08	1570	315	130.0	135.0	148.4	36.0	12.0
9549	0.13		311	130.2	134.0	149.0	33.5	13.0
9550	0.47		311	134.5	137.5	149.0	33.0	12.0
				Mn - Mo				
9564	0.08	1550	311	133.5	140.6	153.2	29.5	11.7
9565	0.16		317	138.7	141.4	153.5	26.5	11.2
9551	0.26		319	140.0	142.5	154.9	21.0	10.0
9566	0.53		317	138.5	140.6	153.6	26.5	11.0

quenched and drawn nickel-chromium-molybdenum steel reported by Mitchell[3], indicates that Heat 9547, the base NE 8630 heat, had properties similar to those tabulated by Mitchell. As compared with the information of Gregg[4], the manganese-molybdenum cast steels, Heats 9564, 9565, 9551, and 9566, are slightly on the low side in regard to ductility, but otherwise the properties are in the expected range.

Tensile Properties of Normalized and Drawn Steels

13. Little change in tensile properties of the normalized and drawn steels took place as the copper content of these steels was increased, except in the case of the NE 8700 type where a significant increase in strength and hardness

Table 4

TENSILE PROPERTIES OF COPPER-BEARING STEELS, NORMALIZED, AND TEMPERED AT 1200° F.

Heat No.	Per Cent Cu	Normalizing Temp. ° F.	BHN	Yield Strength, 1000 psi. 0.1% Offset	Yield Strength, 1000 psi. 0.2% Offset	Tensile Strength, 1000 psi.	Reduction of Area, Per Cent	Elong. in 2 in., Per Cent	Tempering Time Hrs.
				Plain Carbon					
8023	0.02	1580	141	41.7	41.7	76.4	59.5	33.0	1
				NE 9430					
9567	0.06	1550	192	55.6	55.7	93.6	49.5	27.2	2
9568	0.13		197	56.2	56.5	95.0	49.5	24.0	2
9569	0.30		198	59.3	59.1	98.9	49.5	26.0	2
9570	0.53		203	62.3	62.5	97.2	47.5	25.0	2
				NE 8630					
9547	0.08	1570	198	60.7	61.2	92.4	53.0	24.5	2
9549	0.13		197	59.5	60.1	92.5	51.5	21.0	2
9548	0.32		221	....	....	....	....	....	2
9550	0.47		215	67.5	70.0	98.7	46.5	22.0	2
				NE 8700 Type					
8145	0.05	1580	183	72.7	73.5	100.1	57.0	23.0	1
8024	0.46		215	77.7	78.5	104.6	55.5	22.0	1
8022	1.01		232	81.7	84.5	111.2	52.0	20.5	1
8036	1.35		241	89.7	92.3	113.3	49.0	20.0	1
				Mn - Mo					
9564	0.08	1550	215	72.5	72.8	97.6	48.5	19.5	2
9565	0.16		210	74.7	75.1	101.7	44.0	20.0	2
9551	0.26		217	73.7	75.2	102.2	44.5	21.7	2
9566	0.53		217	73.2	73.6	105.1	43.5	21.5	2

and a corresponding drop in ductility occurred with copper additions of 1.01 and 1.35 per cent. A trend in this direction was also noted in the steels containing up to 0.50 per cent, but the evidence in this respect is not too positive. These effects are shown by the data in Table 4.

14. Normalizing of these steels was for a 1-hour period, while the 1200° F. temper was for either one or two hours.

Mechanical Properties of Oil-Quenched and Tempered Steels

15. Tensile and Izod specimens of the series approximating the NE 8700 composition were oil-quenched and tempered at 900, 1050, and 1250° F. An increase in copper up to 1.35 per cent, sufficient to lead to precipitation-hardening phenomena at 900 and 1050° F., so that at those tempering temperatures this phenomenon is superimposed, raised the yield and tensile strength, and hardness of the steel with little or no loss in ductility. This is brought out in Table 5. As in the case of the normalized specimens, the increase in hardness and strength can be associated with the increase in hardenability from the added copper.

Table 5

MECHANICAL PROPERTIES OF OIL-QUENCHED AND TEMPERED COPPER-BEARING CAST STEELS*

(All steels oil-quenched from 1580° F.)

Heat No.	Per Cent Cu	Draw** Temp. ° F.	BHN	Yield Strength 1000 psi. 0.1% Offset	Yield Strength 1000 psi. 0.2% Offset	Tensile Strength, 1000 psi.	Reduction of Area, Per Cent	Elong. in 2 inches, Per Cent	Izod Value Ft.-Lb.
				Plain Carbon					
8023	0.02	900	191	61.5	62.5	96.2	56.0	21.0	38.0
		1050	171	55.3	55.5	89.8	57.5	26.5	44.0
		1200	161	48.7	50.0	80.0	63.5	28.0	46.5
				NE 8700 Type					
8143	0.05	900	325	140.6	145.0	157.8	42.0	10.5	30.5
		1050	282	110.5	114.0	132.6	54.0	17.0	41.5
		1200	231	89.2	90.2	112.0	60.5	21.5	58.5
8019	0.10	900	325	130.6	137.0	157.4	44.5	13.5	26.0
		1050	295	113.3	118.1	137.0	46.5	16.0	44.0
		1200	229	84.7	86.1	110.6	60.5	20.7	63.0
8024	0.46	900	333	146.2	155.2	164.6	43.0	11.3	2.10
		1050	302	123.2	126.2	142.1	50.5	16.7	31.5
		1200	239	94.1	95.0	116.3	59.5	23.7	55.5
8022	1.01	900	363	157.0	162.4	176.1	35.8	13.0	10.0
		1050	304	127.0	129.2	145.1	51.0	18.0	36.0
		1200	244	97.7	98.6	118.0	59.5	22.7	48.0
8036	1.35	900	370	163.6	168.0	181.7	37.0	13.0	6.0
		1050	306	130.2	132.7	149.0	47.5	17.5	27.5
		1200	266	105.1	106.2	123.7	54.0	21.5	47.0

*Average of duplicate tests.
**Steels drawn for one hour.

Charpy Notched Bar Tests at Low Temperatures

16. Considerable evidence has been published to show that very little difference exists in the room temperature properties of fully quenched and drawn steels, provided the steels are at the same hardness, but not much information is yet available regarding the effect of composition on properties at lower temperatures. Until this information is obtained, it cannot be safely assumed that properties at room temperature reflect those at subzero temperatures.

17. A low temperature test on a notched bar of the Charpy or V-notch Charpy type is an enlightening means of investigating low temperature behavior, since it shows differences not revealed by other conventional tests. As the temperature is decreased the curve for ft.-lb. energy absorbed vs. temperature shifts from an upper branch to a lower branch, with tough fractures on the upper and brittle fractures on the lower branch. Over the temperature range in which this shift occurs, there is an inherently large percentage of

Table 6

Low Temperature Charpy* Values of Water-Quenched and Tempered Copper-Bearing Cast Steels

		Charpy Value, ft.—lbs.									
		230 to 250 Brinell					300 to 320 Brinell				
Heat No.	Per Cent Cu	Room Temp.	0° F.	—20° F.	—40° F.	—60° F.	Room Temp.	0° F.	—20° F.	—40° F.	—60° F.
					NE 9430						
9567	0.06	29.0	28.5	29.5	29.5	16.0	18.0	18.0	16.0	17.5	16.0
9568	0.13	31.0	27.0	28.5	28.0	15.0	17.5	16.5	16.0	16.5	15.0
9569	0.30	28.5	29.0	27.0	25.0	16.0	18.0	17.0	17.0	19.0	16.0
9570	0.53	27.0	26.0	27.0	23.5	14.5	16.0	13.5	13.5	13.0	14.5
					NE 8630						
9547	0.08	34.5	32.5	29.0	30.5	18.0	18.5	21.0	18.5	18.0	18.0
9549	0.13	27.5	28.5	28.5	28.0	16.0	17.5	17.5	17.0	16.5	16.0
9548	0.32	27.5	27.5	26.5	26.5	11.5	15.0	15.0	12.0	11.5	11.5
9550	0.47	29.5	25.5	27.0	27.0	13.0	16.0	14.5	13.5	15.0	13.0
					Mn - Mo						
9564	0.08	29.5	26.0	28.0	29.0	15.0	16.0	17.5	15.5	17.0	15.0
9565	0.16	22.0	22.0	20.5	22.0	14.0	17.5	17.0	15.5	16.0	14.0
9551	0.26	31.0	27.0	30.5	28.0	12.5	16.0	14.5	15.0	14.0	12.5
9566	0.53	21.0	19.0	19.5	20.5	12.5	16.0	15.0	14.5	14.5	12.5

*Standard Keyhole notch Charpy bars tested in duplicate.

scatter in the results. The notched-bar test data, therefore, must be viewed from the over-all trend. The bars were heat treated in 0.50-in. x 0.50-in. section, machined, and the notch cut after the treatment.

18. Most castings are much more massive than these slender bars, and a quench that fully hardens the notched-bar specimen may be far from producing full hardening in a large section. The low temperature behavior is vastly influenced by full quenching as against slack quenching. The notched-bar test is here used for, and is in general only applicable for, evaluating behavior of a steel in relation to composition, finishing practice, grain size, etc., under the conventional conditions of the notched-bar test. Behavior in any other structure than that of the small test specimen, in any other size, piece, or with any other notch, may be different, so engineering behavior of an actual casting in actual service is not predicted by the test. However, if this conventional test shows a new steel to behave like a more familiar one, there is reasonable expectation that if the two have similar hardenabilities and are heat treated to the same structure, the new one should closely resemble the old one in engineering behavior.

19. The desired low temperatures were secured with mixtures of dry ice and acetone; specimens were held in the coolant for at least 10 minutes before breaking. The data for the water-quenched and drawn steels are giving in Table 6, and for the normalized and drawn steels in Table 7. The former steels were water-quenched from the draw temperature, while the normalized and drawn steels were either water-quenched or air-cooled from the draw temperature as indicated in Table 7.

Table 7

LOW TEMPERATURE CHARPY* VALUES OF NORMALIZED AND DRAWN COPPER-BEARING CAST STEELS

Heat No.	Per Cent Cu	BHN	Room Temp.	32° F.	0° F.	—20° F.	—40° F.	—60° F.	Al Deoxidation	Coolant after Drawing
					Charpy Value, ft.—lbs.					
					Plain Carbon					
8023	0.02	141	30.5	28.0	23.0	12.5	3.5	3.0	No	Air
					NE 9430					
9567	0.06	192	29.0	....	18.0	20.0	17.0	14.5	Yes	Water
9568	0.13	197	30.0	....	20.0	19.5	16.5	16.0	"	"
9569	0.30	198	29.5	....	20.0	17.0	16.5	14.5	"	"
9570	0.53	203	28.0	....	18.0	16.5	17.5	15.0	"	"
					NE 8630					
9547	0.08	198	29.5	....	20.5	20.5	18.0	15.5	"	"
9549	0.13	197	27.0	....	20.5	19.0	15.5	13.0	"	"
9548	0.32	221	27.5	....	18.5	16.5	16.5	14.5	"	"
9550	0.47	215	27.0	....	18.0	14.5	13.5	13.0	"	"
					NE 8700 Type					
8143	0.05	183	26.0	25.0	20.0	18.5	8.0	3.0	No	Air
8024	0.46	215	31.0	26.5	21.5	21.0	17.5	16.5	"	"
8022	1.01	232	24.5	23.0	19.0	17.0	11.0	3.5	"	"
8036	1.35	241	23.0	22.0	18.0	16.0	15.0	4.0	"	"
					Mn - Mo					
9564	0.08	215	27.5	....	20.0	16.5	16.5	15.5	Yes	Water
9565	0.16	210	24.5	....	20.0	20.0	17.5	15.5	"	"
9551	0.26	217	28.0	....	19.5	17.5	17.0	15.0	"	"
9566	0.53	217	28.5	....	20.0	17.5	14.0	13.5	"	"

*Standard keyhole notch Charpy bars tested in duplicate.

20. Drastic losses in low temperature toughness, above $-60°$ F., occurred only in the normalized and drawn plain carbon steel and in all but one of the steels of the NE 8700. These steels, it will be observed from Table 7, were deoxidized with silicon rather than with aluminum. This effect of dexodization on low temperature toughness has been noted by others[5,6,7,8,] and appears to be a characteristic result of the deoxidization practice. There is no indication from the data that room temperature toughness was reduced by the higher copper addition that was sufficient for precipitation-hardening, as seemed to be the trend for the ductility of the normalized and drawn steel. (See Table 4.) It appears that copper additions, at least up to 0.50 per cent, have no adverse effect on the notched-bar toughness of these cast steels and, on the contrary, may be beneficial. In fact, some evidence was obtained from companion tests on rolled steel that copper tended to lower the temperature at which embrittlement occurred.

21. In the case of the water-quenched and tempered steels, all of which were deoxidized with aluminum, no sudden drop in toughness took place and good Charpy values were obtained down to $-60°$ F. It was observed, however, that specimens tempered to 230-250 Brinell dropped off more rapidly

from −40 to −60° F. than did the specimens tempered to 300-320 Brinell. This difference is brought out in Fig. 2, which gives typical low temperature—Charpy curves for the normalized and drawn and for the water-quenched and drawn steels. The harder specimens from the water-quenched group (circles connected by solid lines) have lower room temperature values, but very little loss in notched-bar toughness occurs down to −60° F. On the other hand, the specimens tempered to 230-250 Brinell have higher room temperature

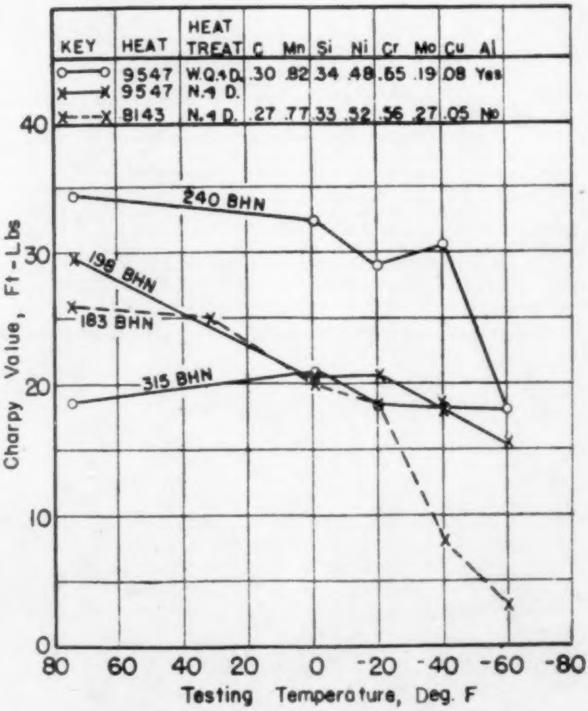
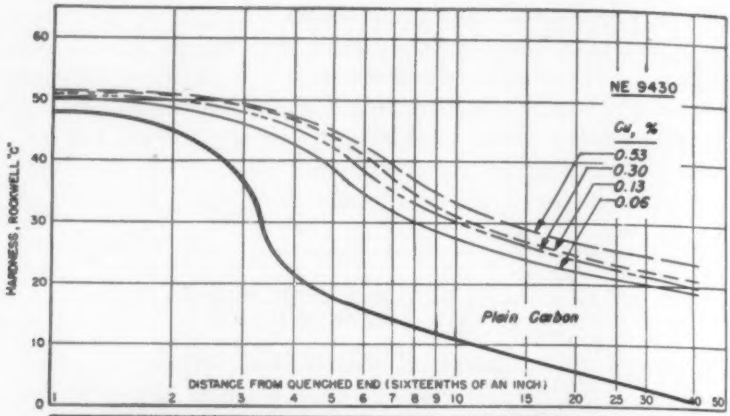


FIG. 2—TYPICAL CHARPY-TEMPERATURE CURVES.

values but lose this difference from −40 to −60° F. The lower toughness of the silicon deoxidized steels at low temperatures, compared to those finished with aluminum, is also illustrated in Fig. 2. All these effects are entirely normal and common to steels of this general class, with or without copper.

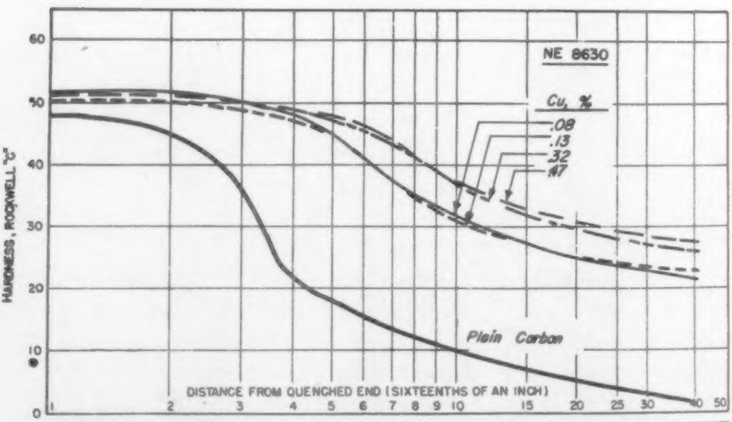
Hardenability Tests

22. End-quench specimens were of the standard size, 1-in. in diameter by 3-in. long. These specimens were heated to about 100° F. above their Ac_3 temperature prior to quenching by placing them in graphite crucibles in a furnace operating at the desired temperature. They reached furnace temper-



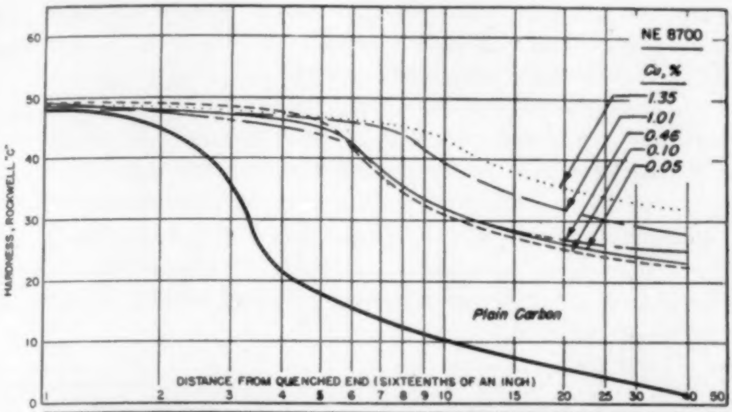
Key	Heat No.	Steel Type	C	Mn	Si	S	P	Cr	Ni	Mo	Al	Cu		Quench Temp.	Grain Size	Remarks
——	8023	C	0.26	0.78	0.31	0.03	0.03	—	—	—		0.02		1580°F	5	
——	9567	NE	0.30	1.04	0.50	.024	.025	0.32	0.32	0.12		0.06		1550°F	6	
- - -	9568	9430	0.30	1.06	0.56	.025	.013	0.26	0.30	0.11		0.13		"	6-7	
-·-·-	9569	"	0.31	1.02	0.46	.025	.012	0.29	0.31	0.11		0.30		"	6-7	
— —	9570	"	0.30	1.04	0.52	.025	.024	0.30	0.33	0.11		0.53		"	6-7	

FIG. 3—END-QUENCH HARDENABILITY CURVES FOR NE 9430 *CAST* STEELS CONTAINING COPPER.



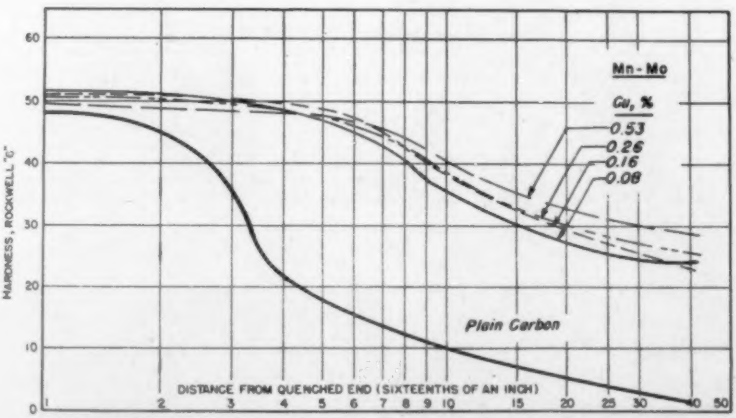
Key	Heat No.	Steel Type	C	Mn	Si	S	P	Cr	Ni	Mo	Al		Cu	Quench Temp.	Grain Size	Remarks
——	8023	C	0.26	0.78	0.31	0.03	0.03						0.02	1580°F	5	
——	9547	NE	.30	.82	.34	.022	.027	.48	.55	.19			.08	1570°F	6-7	
- - -	9549	8630	.29	.76	.33	.022	.029	.50	.52	.20			.13	1570°F	7	
-·-·-	9548	"	.31	.89	.38	.025	.032	.52	.57	.19			.32	1570°F	6-7	
— —	9550	"	.30	.85	.38	.025	.015	.48	.50	.20			.47	1570°F	6-7	

FIG. 4—END-QUENCH HARDENABILITY CURVES FOR NE 8630 CAST STEELS CONTAINING COPPER.



Key	Heat No.	Steel Type	C	Mn	Si	S	P	Cr	Ni	Mo	Al	Cu		Quench Temp.	Grain Size	Remarks
———	8023	C	0.26	0.78	0.31	.03	.03	—	—	—		0.02		1580°F	5	
——	8143	NE	0.27	0.77	0.33	.03	.03	0.56	0.52	0.27		0.05		"	6	
- - -	8019	8700	0.32	0.63	0.41	.02	.03	0.54	0.52	0.26		0.10		"	6	
—-·-·	8024	"	0.28	0.82	0.34	.03	.03	0.53	0.52	0.25		0.46		"	6	
— —	8022	"	0.29	0.76	0.35	.03	.03	0.53	0.53	0.26		1.01		"	5	
·······	8036	"	0.29	0.82	0.34	.03	.03	0.53	0.52	0.25		1.35		"	6	

FIG. 5—END-QUENCH HARDENABILITY CURVES FOR NE 8700 TYPE CAST STEELS CONTAINING COPPER.



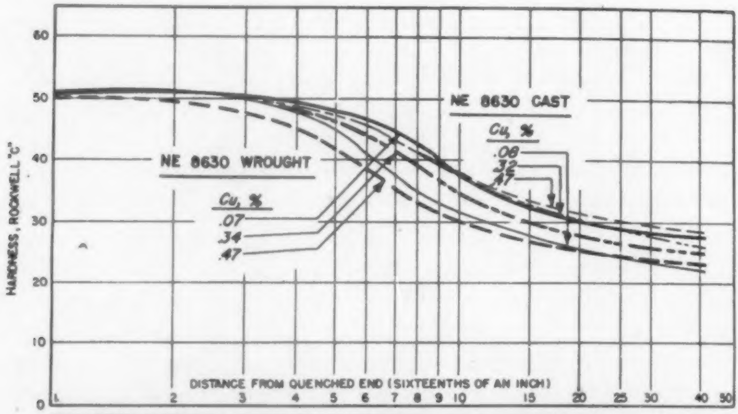
Key	Heat No.	Steel Type	C	Mn	Si	S	P	Cr	Ni	Mo	Al	Cu		Quench Temp.	Grain Size	Remarks
———	8023	C	0.26	0.78	0.31	.03	.03	—	—	—		0.02		1580°F	5	
——	9564	Mn-	0.30	1.49	0.37	.022	.014	—	—	0.35		0.08		1550°F	6-7	
- - -	9565	Mo	0.33	1.67	0.35	.025	.019	—	—	0.34		0.16		"	6-7	
———	9531	"	0.30	1.57	0.37	.025	.018	—	—	0.34		0.26		"	6-7	
— —	9566	"	0.28	1.61	0.35	.022	.024	—	—	0.34		0.53		"	6-7	

FIG. 6—END-QUENCH HARDENABILITY CURVES FOR MANGANESE-MOLYBDENUM CAST STEELS CONTAINING COPPER.

ature within 10 minutes and were held for 20 minutes thereafter, before quenching in a standard end-quench fixture. The procedure used conformed with that in A.S.T.M. Tentative Standard A225-42T.

23. The end-quench curves are plotted in Figs. 3 through 6. The curve for the plain carbon steel, Heat 8023, is included in each case for comparison. Grain size was determined on a fractured face from the quenched end of the end-quench bar by comparing the fracture with Shepherd standard fractures.

24. It should be observed that copper up to 0.50 per cent has but a mild hardening action in the four types of steel being considered. When the copper is raised to 1 per cent or higher, a more pronounced increase in hardenability results as shown in Fig. 5.



Key	Heat No.	Steel Type	C	Mn	Si	S	P	Cr	Ni	Mo	Al	Cu		Quench Temp.	Grain Size	Remarks
———	9534	NE	.29	.89	.34	.032	.029	.49	.53	.23		.07		1570°F	6-7	
—··—	9535	8630	.29	.81	.28	.024	.024	.53	.54	.22		.34		1570°F	6-7	
– – –	10060	"	.30	.78	.28	.029	.031	.52	.27	.22		.47		1570°F	7	
———	9547	"	.30	.82	.34	.022	.027	.48	.55	.19		.08		1570°F	6-7	
—··—	9548	"	.31	.89	.38	.025	.032	.52	.57	.19		.32		1570°F	6-7	
– – –	9550		.30	.85	.38	.025	.015	.48	.50	.20		.47		1570°F	6-7	

FIG. 7—END-QUENCH HARDENABILITY CURVES FOR CAST AND WROUGHT STEEL OF NE 8630 COMPOSITION.

25. According to the work of Grossmann[9], the effect on hardenability from the copper addition of 0.50 per cent should increase the hardenability by a factor of roughly 1.18. For a steel having an initial manganese content of 0.80 per cent, this increased copper would be roughly equivalent to a manganese increase of 0.20 per cent. This percentage increase in manganese corresponds to the usual allowable range for this element. Consequently, unless residual copper is unusually high in the scrap, the effect of copper on the hardenability of the steel will be slight, but if it is high, its hardening effect can be utilized by slightly lowering the percentages of other alloying elements to compensate for this increase in copper.

26. Hardenability curves for cast and wrought steels of similar composition

are plotted in Fig. 7. It is seen from this figure that a recognizable difference in hardenability exists between these particular cast and wrought specimens having the same copper content. However, these differences very likely result from small differences in composition (particularly manganese) that are evident in the comparable steels. If these differences were removed, it would be expected that the hardenability curves for the cast and wrought steels of the same copper content would be practically identical.

SUMMARY

27. In tests on four different alloy steels, three of which corresponded to NE grades, the presence of copper up to 0.50 per cent did not change the tempering temperature required to obtain the desired hardness in full quenched specimens. Thus, if copper is present as a residual in an alloy steel, no adjustment in tempering temperature is necessary. When normalized, however, the steels showed a mild increase in as-normalized hardness as copper was raised from 0 to 0.50 per cent. Tempering these steels above 1000° F. markedly reduced the effect of copper on hardness. The hardness after normalizing appeared to be related to the hardenability of the steels.

28. Copper up to 0.50 per cent induced no change in tensile properties of fully quenched and drawn steels. When present in amounts above 1 per cent, there was an increase in strength and a corresponding drop in ductility in normalized steels, and heat treatment suitable for developing precipitation-hardening brings in the usual precipitation-hardening behavior of steels at this copper level. Low temperature toughness of alloy steels is not greatly influenced by copper in percentages up to 0.50. The type of deoxidization treatment is extremely important in determining the temperature at which low temperature brittleness will occur.

29. Copper has a mild hardenability effect in an alloy steel, and if present in appreciable amounts, it can be used as a partial substitute for some other alloying element in applications where hardenability is a major factor.

ACKNOWLEDGMENT

30. Grateful acknowledgment is made to Anaconda Copper Mining Company, Phelps-Dodge Corporation, and Kennecott Copper Corporation, sponsors of the investigation, for permission to publish the results.

BIBLIOGRAPHY

1. Walter G. Patton, *"Mechanical Properties of NE, SAE, and Other Hardened Steels."* METAL PROGRESS, vol. 43, May, 1943, pp. 726-734.

2. E. J. Janitzky and M. Baeyertz, *"The Marked Similarity in Tensile Properties of Several Heat Treated SAE Steels."* A.S.M. HANDBOOK, 1939 Edition, pp. 515-518.

3. H. A. Mitchell, *"Getting the Most Out of Steel Castings."* THE IRON AGE, vol. 126, 1930, pp. 914-917.

4. A. W. Gregg, *"Production of Alloy Castings."* TRANSACTIONS, AMERICAN FOUNDRYMEN'S ASSOCIATION, June, 1934, p. 56.

5. C. H. Herty, Jr., and D. L. McBride, *"Effect of Deoxidization on the Impact Strength of Carbon Steels at Low Temperature."* MINING AND METALLURGICAL INVESTIGATIONS. CARNEGIE INSTITUTE OF TECHNOLOGY AND MINING, AND METALLURGY ADVISORY BOARDS, Cooperative Bulletin 67, 41 pp.

6. A. B. Kinzel, Walter Crafts, and John J. Egan, *"Fine-Grained Structural Steels for Low-Temperature Pressure-Vessel Service."* METALS TECHNOLOGY, A. I. M. E., T.P. 800, vol. 4, 24 pp. (1937).

7. C. H. Herty, Jr., *"The Effect of Deoxidation on Some Properties of Steel."* TRANSACTIONS, AMERICAN SOCIETY FOR METALS, vol. 23, pp. 113-121 (1935).

8. C. E. Sims and F. B. Dahle, *"Comparative Quality of Converter Cast Steel."* AMERICAN SOCIETY FOR TESTING MATERIALS, Preprint No. 29, 1942, 19 pp.

9. M. A. Grossmann, *"Hardenability Calculated from Chemical Composition."* AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS, Technical Publication No. 1437.

DISCUSSION

Presiding: C. H. LORIG, Battelle Memorial Institute, Columbus, Ohio.

Co-Chairman: H. F. TAYLOR, Naval Research Lab., Anacostia Station, Washington, D. C.

CO-CHAIRMAN TAYLOR: Would the possible difference in the hardenability that you noticed between the wrought and the simultaneously cast material be due to the fact that you cast your ingot in an ingot mold and the casting in sand? We cast both in sand. Do you suppose that could account for the difference?

MR. GREENIDGE: I would not expect it to unless there was considerable segregation in either the ingot or the sand casting. The ingot we cast was pretty small, so there is not much chance of segregation in it. The test bar was a two-legged test bar with about 1¼-in. legs which also would freeze rather rapidly.

CO-CHAIRMAN TAYLOR: Are you correcting for grain size?

MR. GREENIDGE: The cast and wrought steels were of about the same grain size. It has been our experience that the cast steel runs slightly lower in hardenability than the wrought steel.

CHAIRMAN LORIG: This question of hardenability is very interesting. I am really amazed at the correlation between the calculated and the actual hardenabilities, because occasionally there are steels which, for some unknown reason, do not behave according to any hardenability formula. Has anyone had experience with steels of such compositions that, according to calculation, should have certain hardenability values but which fall far short from the calculated values?

The Four-Part Cheek Method of Producing Cast Iron Cylinders

By Robert Hendry*, Beloit, Wisc.

Abstract

War production has made many unusual demands. When the facilities of the Beloit Iron Works, which specialized in manufacturing paper machinery in the pre-war era, had to be converted to building marine steam engines, a method of production, combining speed with efficiency, had to be adopted—this was the 4-Part Cheek Method, described in the accompanying article.

When the United States entered the present World War, it was known that thousands of ships would be required—some to carry supplies to our far-flung battle fronts, and others to guard their precious cargoes, so necessary to the success of our armed forces. Ship building became a "must."

As the ship building tempo increased, a demand was generated for steam engines for propulsion of certain types of ships. Cast iron foundries were contacted and confronted with the problem of producing high, medium and low pressure cylinders for such steam engines on a production basis. Various foundries adopted different methods of production.

When the company with which the writer is associated was asked to make low pressure steam cylinders, it realized that, due to design of the cylinders desired, it was likely to encounter trouble. Representatives of the company visited a number of foundries already engaged in building steam engines and using cylinders of the same type as requested from our company, but with larger diameter bore.

Molding Methods Studied

As a result of observations in the foundries visited, it was discovered that at least five different methods were utilized for molding the cylinders. Some foundries used all cores on the outside and cast the cylinder on end; others used a cheek split into two parts, bottom and top halves. Our representatives found that less scrap castings were made when the castings were molded by the cheek method.

In one foundry visited which used the cheek method, the cores were set in the drag, then the bottom half of the cheek was set on the drag over the cores. The top half of the cheek then was placed in position and the remainder of the cores set into the mold.

Due to the depth of the mold and to the cores being placed one on top of the other, it was necessary that chaplets be used. In addition, considerable dirt collected in the mold, regardless of how carefully the molder set the cores.

As these cylinder castings were required to withstand water pressure, elimination of dirt was very impor-

*Beloit Iron Works.

Note: This paper was presented at a Gray Iron Castings Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 26, 1944.

tant. Also, due to the design of the outside portion of the casting, cores had to be used, because of the manner in which the pattern had to be drawn from the cheek.

MANY CORES ELIMINATED

As a result of visits to various foundries, it was decided that, if a 4-part cheek method of molding was used, many cores would be eliminated. In addition, by ramming the cheeks in the foundry, using molding sand, production pressure—at that time extremely heavy in the core room—would be relieved.

The company with which the author is associated undertook the manufacture of the low pressure cylinder, shown in Fig. 1. As previously stated, our foundry decided to use the 4-part cheek method, as it permitted the internal cores to be set into place before the mold itself was completed, and eliminated the use of chaplets at vital parts of the casting.

Equipment used in the 4-part cheek method, shown in Table 1, consisted of drag, cheek and core flasks, cope and drag patterns mounted on boards, and 27 core boxes of various types. The following is a step-by-step illustrated description of the molding of the previously mentioned low pressure cylinder:

FIG. 1—VIEW OF CAST IRON, LOW PRESSURE STEAM CYLINDER CASTING.

Table 1

EQUIPMENT USED IN 4-PART CHEEK METHOD

Flask	Drag—60x94x13 in. Cheek—60x94x43 in. when bolted together at corners. Cope—60x94x13.
Pattern	Cope and drag patterns mounted on boards. 2 core boxes for cheek ends. 2 core boxes for cheek sides. 4 core boxes for port cores. 1 half cylinder core box. 2 core boxes for foot lightening cores. 10 small core boxes. 6 cover core boxes.

MOLDING THE DRAG

Fig. 2 shows the drag flask resting on the drag pattern board with the molder filling the flask for ramming. Weights are placed on the loose flange cover core prints. Pockets under the flanges are secured with rods and gaggers. Fig. 3 shows the molder removing cover core prints and loose flanges. Cover cores are set before the drag is rammed to completion. Fig. 4 shows the drag pattern being drawn, and Fig. 5 shows the completed drag after it has been washed, but before drying.

RAMMING CHEEK CORES

Core boxes for the side cheek core are approximately 43 x 60 x 21 in. and are rammed with molding sand in the foundry. Arbors are

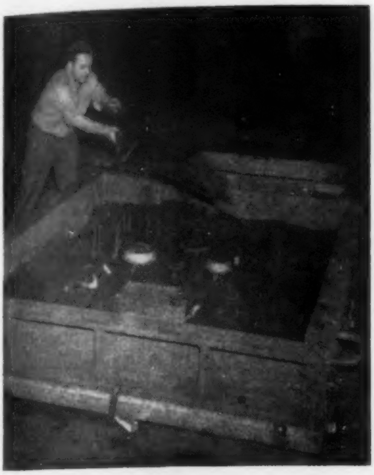


FIG. 2—DRAG FLASK RESTING ON DRAG PATTERN BOARD.

FIG. 3—REMOVING COVER CORE PRINTS AND LOOSE FLANGES.

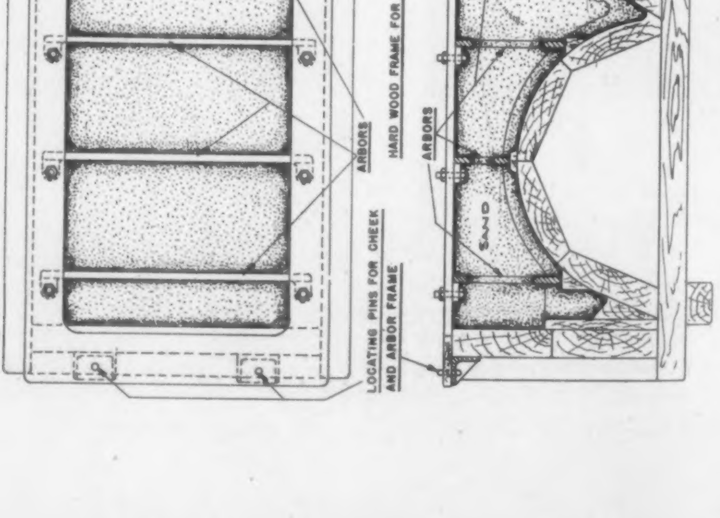
placed in the boxes and are located and bolted to a hard-wood frame, as shown in Fig. 7.

Fig. 6 shows the side cheek core being rammed. Note the gaggers used to secure the core. Fig. 8 illustrates a cross-section of the core box with arbors and cheek flask side located, and the assembly ready to be rolled over. Fig. 9 shows a cross-section of the completed side cheek core with the location of arbors indicated.

Fig. 10 shows a side of cast iron flask cheek being located on the side cheek core box by loose pins, while Fig. 11 shows the arbors being bolted to the flask cheek. (See Fig. 8 for details.)

FIG. 4—DRAWING THE DRAG PATTERN.

FIG. 5—COMPLETED DRAG.



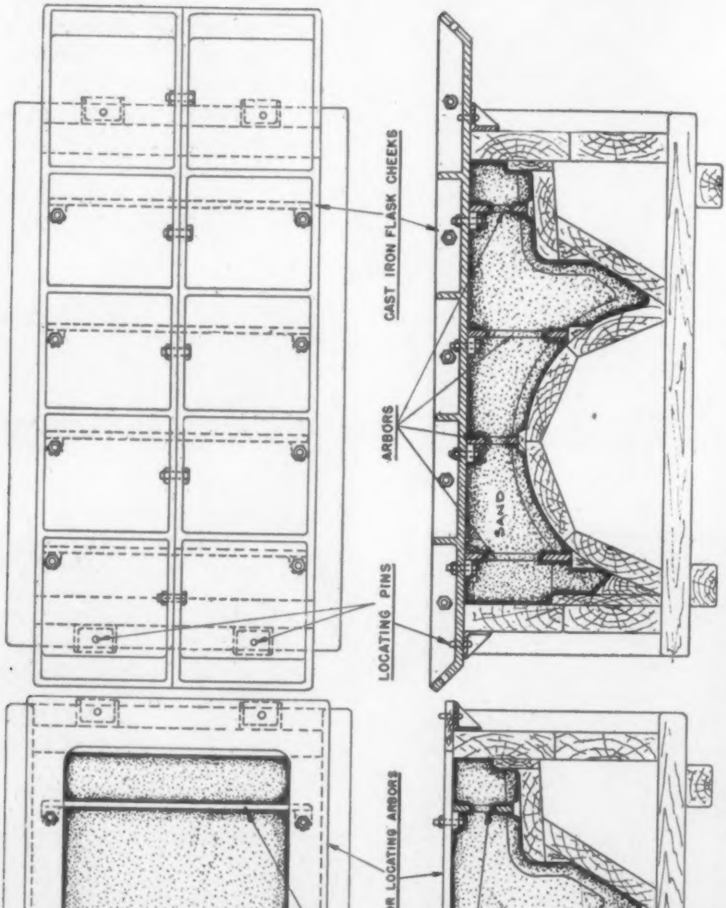


FIG. 7—LEFT—CROSS SECTION OF SIDE CHEEK CORE SHOWING ARBOR LOCATIONS AND METHOD OF LOCATING THEM.
FIG. 8—RIGHT—CROSS SECTION OF CORE BOX SHOWING SIDE CHEEK CORE ARBORS BOLTED TO SIDE CHEEK FLASK SECTION.

Fig. 12 shows another view of the drawing operation and also depicts the dry sand cores used as down gates. These cores are rammed up in the core box and are located by holes and loose plugs in the side of the core box. Fig. 13 shows the completed core being washed, prior to drying.

The operations in making the end cheek cores are not shown, as the procedure is exactly the same as that used to make the side cheek cores. End cheek core boxes are approximately 43 x 60 x 14 in., as compared with 43 x 60 x 21 in. for the side cheek core boxes.

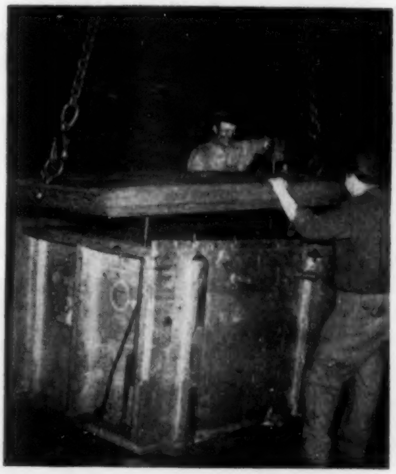


Fig. 10—Locating Side of Cheek Flask on Cheek Core Box.

Fig. 6—Ramming Side Cheek Core.

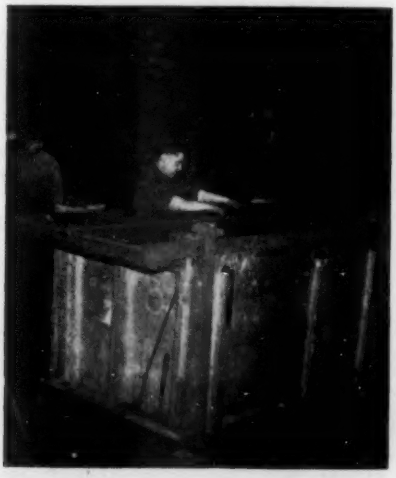


Fig. 11—Bolting the Arbors to the Side Cheek Flask Section.

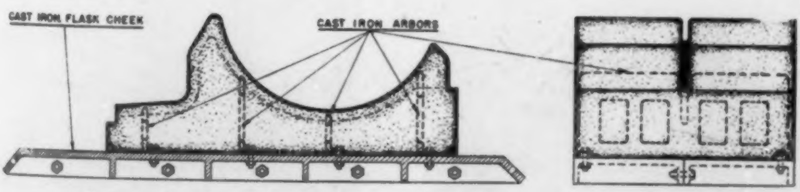


Fig. 9—Cross Section of Completed Side Cheek Core Mounted on Side Cheek Flask Section.

SETTING CHEEK AND CORES IN DRAG

After the side and end cheek cores are made, assembled on their respective parts of the four-part cast iron cheek flask properly coated with wash and dried, the next operation in the molding procedure is setting the cheek sections and the cores on the drag. Fig. 14 shows an end cheek being located on the drag. The end cheek is bolted into position on the drag flask.

Fig. 15 shows the port cores in position. These port cores are guided into position by the core print impression (Fig. 14) in the cheek end of the assembly. Two

FIG. 12—SIDE CHEEK CORE. NOTE DRY SAND CORE DOWN GATES.

FIG. 14—END CHEEK ASSEMBLY BEING LOCATED ON DRAG.

FIG. 13—WASHING COMPLETED CORE.

FIG. 15—PORT CORES IN POSITION.

lightening cores for the feet are bolted to the drag mold by tapped plates, which are rammed into the loose flange cover core. Fig. 16 shows the arrangement of port cores in the mold. Fig. 17 shows the cylinder diameter core being set.

Fig. 18 shows the side cheek in level position suspended from the crane and ready to be placed on, and bolted to, the drag. Fig. 19 shows the side cheeks being placed in position.

Fig. 20 illustrates the method

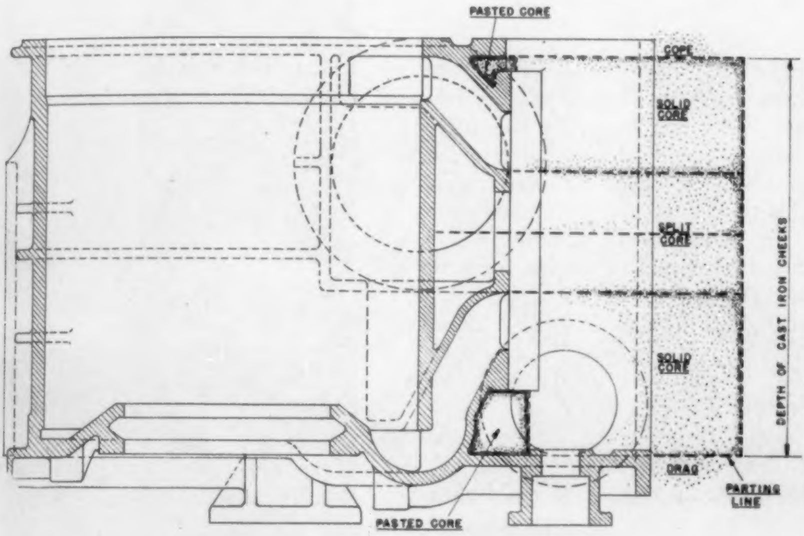


Fig. 16—Section Showing Port Core Arrangement.

Fig. 17—Setting Cylinder Diameter Core.

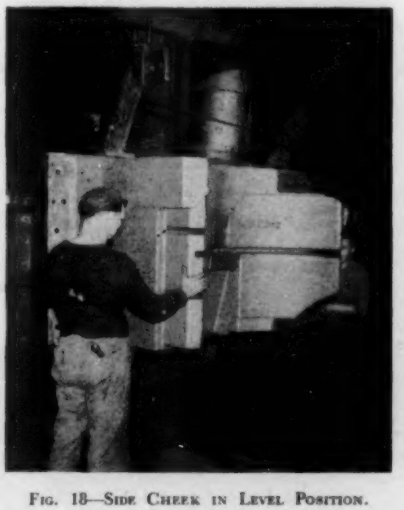


Fig. 18—Side Cheek in Level Position.

used to check wall thickness. Note the feeler gage being used to secure accurate mold dimensions. In Fig. 21 the other end cheek is being placed in position to complete the cheek assembly. When the final end has been correctly positioned, the cheek flask sections are bolted together at the corners and also to the drag flask.

Fig. 22 shows a sketch of the cheek assembly. Note that the sections were left open at the mold joints. These sections were rammed up after the cheek was assembled. This procedure eliminated run-outs.

Fig. 23 shows the assembled drag and cheek ready to receive the cope and Fig. 24 shows the cope being located onto the drag and cheek assembly. The cope is equipped with special bars and a ring for locating shower gates.

Fig. 25 shows the shower gates and runner being placed in position, while Fig. 26 shows the mold completed and ready for pouring.

FIG. 19—LOCATING SIDE CHEEK ON DRAG.

FIG. 20—CHECKING THE MOLD ASSEMBLY FOR CORRECT SECTION THICKNESS.

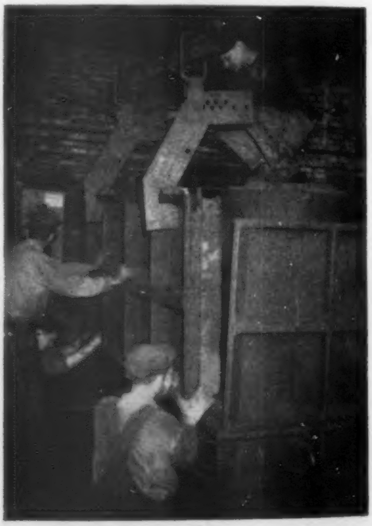


FIG. 21—FINAL END CHEEK BEING PLACED IN POSITION.

CONCLUSION

The foundry with which the author is associated has found the method outlined above to be particularly efficient for the production of the low pressure steam cylinders

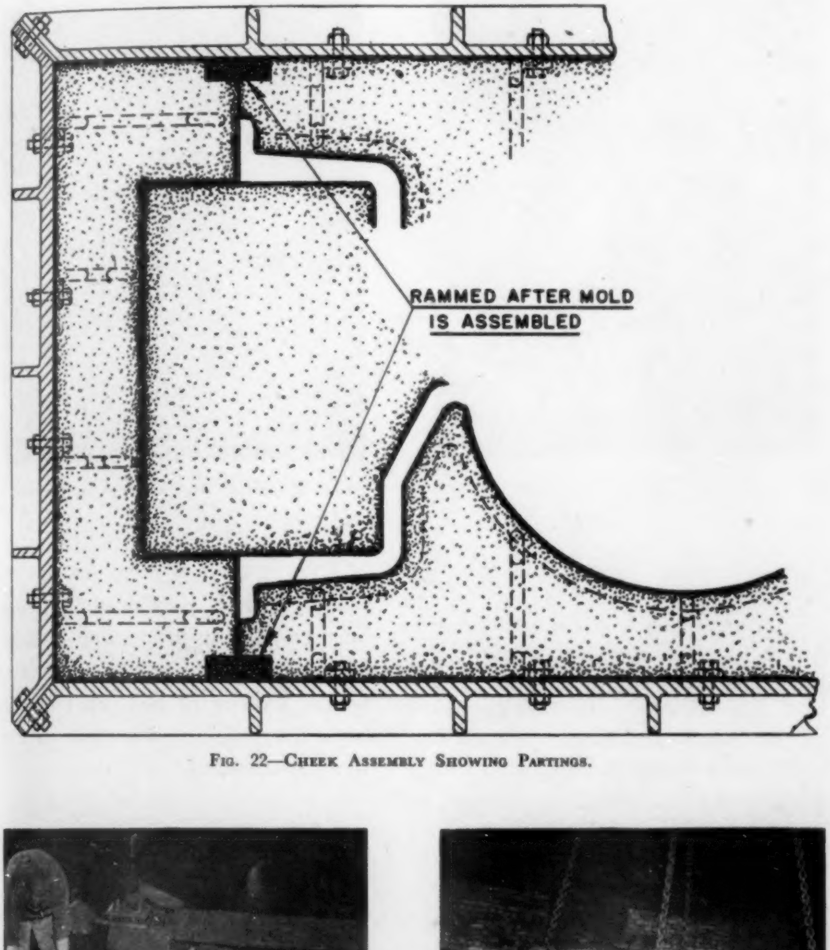


FIG. 22—CHEEK ASSEMBLY SHOWING PARTINGS.

FIG. 23—DRAG AND CHEEK ASSEMBLY WITH CORES IN POSITION FOR CLOSING.

FIG. 24—LOWERING COPE.

FIG. 25—PLACING GATES AND RUNNER IN POSITION.

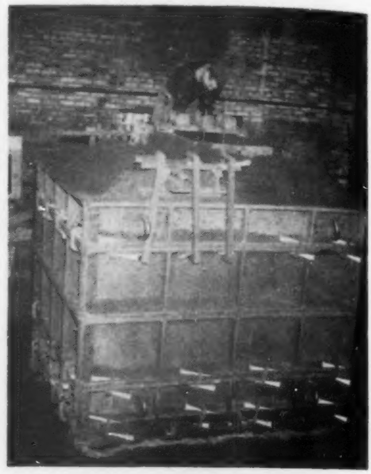


FIG. 26—MOLD ASSEMBLED AND READY FOR POURING.

indicated. The castings produced by this method are clean and pass the water test without failure. Time saved in making cylinder castings by the method outlined is so good that this job has proved to be one of the best in the shop when computed on a tons-per-hour basis.

This method is given to the industry, as it is possible that it may be used for the production of similar castings, especially in cases where a series of built-up cores on both the inside and outside of the mold is required.

The Utilization of Fired Cartridge Brass in Cast Manganese Bronze†

By John T. Robertson*, Washington, D. C.

Abstract

Fired cartridge brass can be used in the manufacture of low tensile cast manganese bronze with no serious harm to the mechanical properties provided that the antimony content is not more than 0.01 per cent. This percentage was not found in any manganese bronze made from 20 millimeter, 40 millimeter and 0.50 calibre cases.

1. The utilization of fired cartridge brass is a problem of increasing importance. For a number of months there has been a growing accumulation of unused scrap of this type. One of the principal objections to its use has been contamination by small percentages of antimony and lead from the priming charge. Previous investigators have pointed out the dangers of excessive amounts of these elements to the mechanical properties of wrought 70-30 brass. Little mention has been made in the literature of the influence of antimony in the presence of lead on cast manganese bronze containing the percentages of antimony usually found in fired cartridge brass.

2. The purpose of the present investigation was to find a casting alloy which could be made from fired cartridge scrap and whose mechanical properties would not be unduly impaired by the small percentages of impurities. Cast manganese bronze would appear ideal for this purpose because its manufacture from fired cartridge scrap consists merely of adding suitable hardeners and about 10 per cent of zinc to the melt of 70-30 brass. The use of fired cases depends not only upon the amount of antimony in the cartridge brass compatible with good mechanical properties of the manganese bronze, but also upon many other factors beyond the scope of the present investigation.

Previous Work on the Effects of Antimony and Lead

3. Hull, Silliman, and Palmer[1] have reported that 0.007 per cent of antimony and 0.07 per cent of lead were present in remelts of fired small arms cartridge cases. They stated that 70-30 brass containing 0.05 to 0.10 per cent of antimony was difficult to cold roll. In the same investigation, hot rolling

---

†Published by permission of the Navy Department.

*Ensign, U. S. N. R., Naval Research Laboratory, Anacostia Station, Washington, D. C.

Note: This paper was presented at a Brass and Bronze session of the 48th annual meeting, American Foundrymen's Association, Buffalo, N. Y., April 26, 1944.

[1]Superior numbers refer to references at end of paper.

was found to be limited by 0.01 to 0.02 per cent of antimony. The presence of lead in amounts less than 0.1 per cent greatly accentuated the effect of the antimony. It was also found that the impact strength of 70-30 brass as measured by the Charpy test was lowered by the addition of 0.01 per cent of antimony. Lynes[2] reported that 0.1 per cent of antimony increased the notch sensitivity of a 70-30 brass rod, but that 0.03 per cent of antimony did not have this effect.

4. Rae[3] stated that for 0.303 calibre cases the antimony is one per cent of the weight of the unfilled cases. While this is higher than the percentage found in the present investigation, it is true that the smaller the case the greater the ratio of weight of antimony to weight of case. Rae also reported that in heats of alpha-beta brasses using 60 per cent fired cases, Izod impact values dropped sharply. He found that heating the cases in a muffle furnace at 500 to 600° C. for 10 min. to explode any unfired cases had no effect on the amount of antimony in the final alloy.

5. Rolfe[4] showed that additions of over 0.75 per cent of antimony to Admiralty gun metal (88 per cent copper, 10 per cent tin and 2 per cent zinc) lowered the tensile strength and elongation below Admiralty specifications. Gardner and Saeger[5] found that up to 0.25 per cent antimony had no significant effect on the physical properties of 85-5-5-5 alloy (85 per cent copper, 5 per cent each of tin, lead and zinc).

EXPERIMENTAL PROCEDURE

Antimony and Lead on Surface of Cases

6. Fired cartridge cases were obtained from the Washington Navy Yard, the St. Louis Arsenal and the Frankford Arsenal; and were segregated according to period and place of manufacture. The cases from the arsenals were 0.50 cal., and those from the Navy Yard were 20 mm. and 40 mm. Sample cartridge cases from each group were sectioned lengthwise and analyzed spectrographically by the spark method for lead and antimony at various places on the inside surface of the case (Fig. 1). The percentages reported are on a comparative basis for equal times of sparking. In all of the cartridge cases the percentage of antimony was highest (about 0.05 per cent) near the primer end and gradually decreased toward the neck. The distribution of the lead was similar.

Lead and Antimony Present in Remelted Cases

7. To determine the antimony retained in melting fired cartridge brass, 5-lb. heats of each type of case were melted in a graphite crucible in an induction furnace. No cover was used because the walls of the crucible provided sufficiently strong reducing conditions. As soon as the metal was melted, it was stirred and the power shut off. The crucible was then removed from the

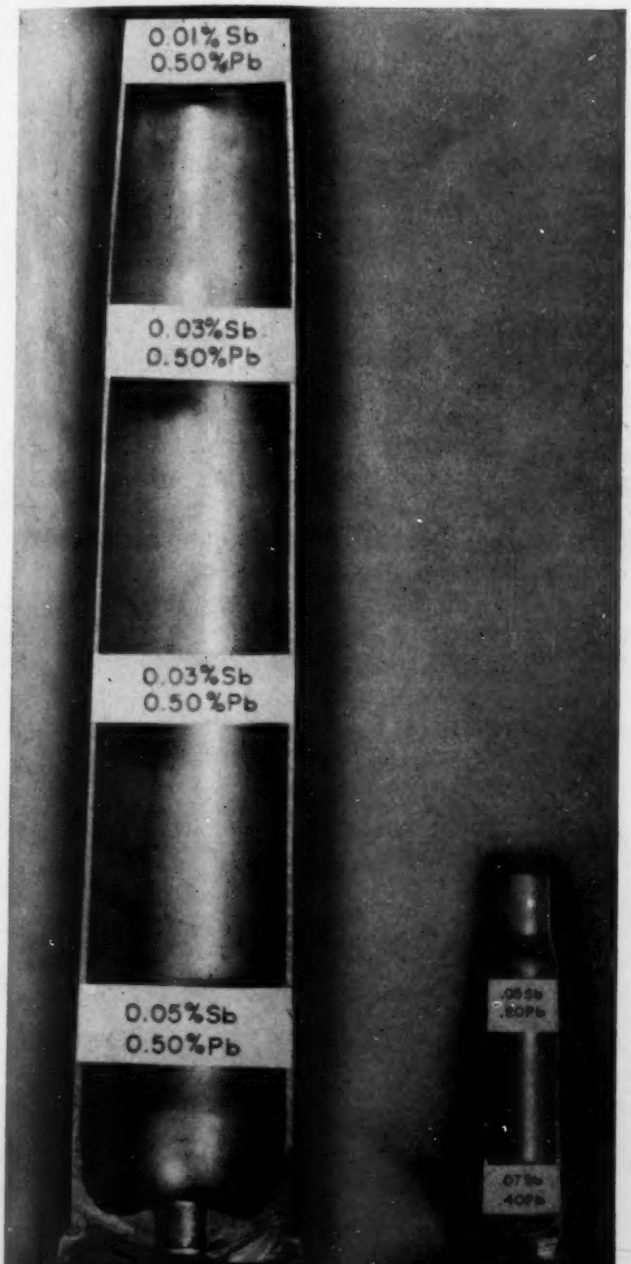


Fig. 1— Distribution of Lead and Antimony on the Inside Surface of Fired Cartridge Cases (40 mm. and 0.50 Cal).

furnace and the metal allowed to solidify in the crucible. Samples for spectrographic analysis were taken from corresponding positions at the center of each ingot. The compositions of melts of fired cases are shown in Table 1.

Table 1

COMPOSITION OF MELTS OF FIRED CASES

Type of Case	*Per Cent Sb*	*Per Cent Pb*
50 calibre (F. A. 1940-43)	0.002	0.005
50 calibre (F. A. 1932-39)	0.003	0.007
50 calibre (S. L. A. 1940)	0.003	0.010
20 millimeter	0.002	0.002
40 millimeter	0.003	0.005
Cleaned cases	0.003	0.003

Cleaning Cartridge Cases by Chemical Methods

8. An investigation was carried out on chemical cleaning of the cases with aqueous solutions of sodium hydroxide, sodium cyanide, cream of tartar, and chromic acid. The effects of time, temperature, and concentration were studied. The most suitable conditions were found with a solution of 25 per cent chromic acid and 0.5 per cent sulfuric acid used at room temperature with a leaching time of 10 min. Spectographic analysis before and after this test showed that the antimony on the inside surface of the cases decreased from 0.05 per cent to less than 0.005 per cent. A few 5-lb. heats of cleaned cases were melted and an analysis of the metal showed the antimony and lead content to be approximately the same as that obtained when uncleaned cases were melted. In view of this fact, work on methods of cleaning was discontinued.

Manganese Bronze Made from Fired Cases

9. Five heats of manganese bronze were made from fired cartridge cases in order to investigate the suitability of fired cases as a charge for making this alloy. One heat was made using all three types of cases available, two heats were made from 50 cal. cases, and two heats from 40 mm. cases.

Melting Practice

10. The fired cases were melted in a clay-graphite crucible in an induction furnace under a charcoal cover. In the first heat the iron and aluminum were added in the form of a 50-50 master alloy, which melts at approximately 1150° C. (2100° F.). This required heating the brass to such a high temperature that zinc flaring became excessive. In the other four heats the iron-aluminum master alloy was melted separately and added molten to the brass, which was at a temperature of 1050° C. (1920° F.). Zinc flaring was caused by the addition of the molten master alloy, but was not as severe as it was in

the first heat. The manganese was added as 50-50 copper manganese and the zinc and tin as virgin metals.

Effect of Antimony on Manganese Bronze

11. Several heats of manganese bronze were made from virgin metals for the purpose of determining the effects of antimony on the mechanical properties. Two 200-pound heats were made having the following nominal composition:

Component	*Per Cent*
Copper	58.00
Zinc	39.0
Iron	1.0
Aluminum	1.0
Manganese	0.5
Tin	0.5

This metal was remelted in forty-pound lots and antimony added in amounts up to 0.20 per cent. All melts were poured at 990±10° C. (1814±18° F.) into bottom-fed "separately cast bar" tensile molds prepared in accordance with N.D. Specification 49-B-3e. The molds, which were made of no. 00 Albany sand containing about 6 per cent moisture, were allowed to air dry for at least 24 hr. before using. The castings provided sufficient metal for two standard 0.505 in. tensile bars, chemical samples, and specimens for spectrographic analysis.

Discussion of Results

Effect of Antimony and Lead on Use of Remelted Cases

12. As shown by the analyses in Table 1, the percentages of lead and antimony remaining in remelted cases were of the same order of magnitude as in the virgin metal. These percentages were far below the minimum which would be harmful to the cold-rolling properties of 70-30 brass, as stated by Hull, Silliman and Palmer[1].

13. The manganese bronze made from fired cartridge cases met Navy Specifications 49-B-3e. Some of these heats had a tensile strength of 77,000 psi. with an elongation of 23 per cent. Since this elongation was only three per cent above the minimum specified, an attempt was made to obtain a higher elongation with a lower tensile strength by adjustinging the composition of the bronze. When this was done, a tensile strength of 70,000 psi. and an elongation of 37 per cent were obtained (Table 2).

14. The addition of antimony to manganese bronze made from virgin metals was found to decrease the tensile strength and elongation. The metal will not meet specifications if there is more than 0.01 per cent antimony present (Table 3 and Fig. 2). This percentage was not found in any of the manganese bronze made from fired cartridge cases.

Table 2

COMPOSITION AND MECHANICAL PROPERTIES OF MANGANESE BRONZE MADE FROM FIRED CARTRIDGE CASES

Heat No.	*Type of Case*	*Composition, Per Cent*								*Mechanical Properties*		
		Cu	*Zn**	*Sn*	*Fe*	*Al*	*Mn*	*Sb*	*Pb*	*Yield Strength, psi. (0.1 Per Cent Offset)*	*Tensile Strength, psi.*	*Elongation, Per Cent in 2 in.*
E25	50 cal.	57.86	39.17	0.49	0.95	0.90	0.68	<0.005	0.02	40,000	77,000	22.7
E25A	50 cal.	57.86	39.17	0.49	0.95	0.90	0.68	<0.005	0.02	40,200	77,200	23.0
E24	40 mm.	58.91	38.38	0.51	0.77	0.68	0.82	<0.005	0.005	30,000	70,200	37.0
E24A	40 mm.	58.91	38.38	0.51	0.77	0.68	0.82	<0.005	0.005	27,500	70,500	38.0
E21	Mixture	57.39	39.72	0.55	0.80	0.89	0.65	0.005	0.005	32,500	76,000	21.1

*By difference.

Table 3

Effect of Antimony on Mechanical Properties of Cast Manganese Bronze

Heat No.	Composition, Per Cent								Mechanical Properties		
	Cu	*Zn*†	*Sn*	*Fe*	*Al*	*Mn*	*Pb*	*Sb*	Yield Strength, psi. (0.1 Per Cent Offset)	Tensile Strength, psi.	Elongation, Per Cent in 2 in.
B77	58.87	38.49	0.46	0.77	1.03	0.38	*	*	41,600	73,000	32.5
B78	58.42	38.80	0.55	0.80	1.04	0.39	*	*	44,500	75,000	25.0
B79	58.53	38.56	0.56	0.84	1.07	0.44	*	*	44,100	73,300	23.0
B82	58.88	38.22	0.56	0.82	1.07	0.38	*	0.07	42,200	63,000	13.5
B83	58.22	38.86	0.56	0.82	1.09	0.40	*	0.05	46,100	64,800	11.0
B84	58.25	38.83	0.57	0.82	1.07	0.40	*	0.06	47,100	61,700	7.5
B85	58.91	38.33	0.52	0.84	0.91	0.40	*	0.09	44,900	64,400	12.5
B86	58.84	38.32	0.56	0.89	0.92	0.39	*	0.08	47,500	62,300	6.5
B87	58.40	38.74	0.52	0.86	1.0	0.39	*	0.09	48,500	61,800	7.0
B88	58.72	38.32	0.55	0.84	0.97	0.41	*	0.19	44,000	56,000	9.0
B89	58.00	39.00	0.56	0.90	0.99	0.40	*	0.15	48,200	57,200	6.5
B90	58.35	38.62	0.49	0.90	1.04	0.40	*	0.14	46,000	56,000	8.0
E7	56.58	40.97	0.39	0.89	0.65	0.52	0.001	<0.005	36,000	77,700	27.0
E8	56.49	40.89	0.52	0.93	0.65	0.52	0.008	<0.005	41,000	76,000	18.0
E10	56.74	40.83	0.30	0.88	0.67	0.58	0.04	<0.005	34,000	75,300	17.5
E11	56.04	41.42	0.61	0.88	0.62	0.54	0.03	0.04	39,400	62,300	5.3
E12	56.22	41.06	0.61	0.86	0.68	0.57	0.09	0.10	39,500	59,200	3.7
E21	57.39	39.72	0.55	0.80	0.89	0.65	0.005	0.005	35,000	75,700	21.1

*No analysis was made.
†By difference.

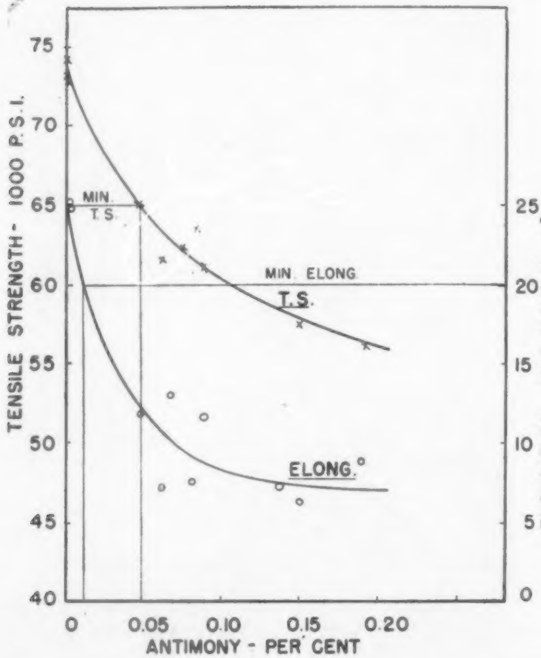


FIG. 2—EFFECT OF ANTIMONY ON TENSILE STRENGTH AND ELONGATION OF MANGANESE BRONZE.

SUMMARY AND CONCLUSIONS

15. Manganese bronze which will meet Navy Specifications 49-B-3e can be made from fired cartridge cases.

16. The elongation of manganese bronze is sharply lowered if there is 0.01 per cent of antimony present. This percentage was not found in any of the manganese bronze made from fired cartridge cases including 20 mm., 40 mm., and 0.50 cal. cases.

ACKNOWLEDGMENTS

17. The author wishes to express his appreciation to Dr. Blake M. Loring for his help and encouragement, and to L. Singer for the chemical analyses.

Bibliography

1. Hull, D. R., Silliman, H. F., and Palmer, E. W., TRANSACTIONS, American Institute of Mining and Metallurgical Engineers, vol. 152, p. 127 (1943).

2. Lynes, W., *"Comparative Value of Arsenic, Antimony and Phosphorus in Preventing Dezincification,"* PROCEEDINGS, American Society for Testing Materials, vol. 41, p. 876 (1941).

3. Rae, J., Jr., *"The Use of Fired Small-Arms Cartridge Cases in the Production of*

Some Alpha-Beta Extrusion Brasses: Indications of the Effects on the Physical Properties of the Extruded Rods," Journal, Institute of Metals, vol. 48, p. 311 (1942).

4. Rolfe, R. T., *"The Effect of Increasing Proportions of Antimony and of Arsenic, Respectively, Upon the Properties of Admiralty Gun-Metal,"* Journal, Institute of Metals, vol. 24, p. 260 (1920).

5. Gardner, H. B., and Saeger, C. M., *"The Effects of Aluminum and of Antimony on Certain Properties of Cast Red Brass,"* Journal of Research, National Bureau of Standards, vol. 22, p. 707 (1939); and Transactions, American Foundrymen's Association, vol. 47, pp. 423-449 (1939).

DISCUSSION

Presiding: L. M. Long, Leighton M. Long & Associates, Toledo, Ohio.

Co-Chairman: C. O. Thieme, H. Kramer & Co., Chicago, Ill.

G. P. Halliwell[1] *(written discussion):* The yield strengths shown for heats B77 to B79 inclusive in Table 3 appear to be somewhat high, especially when considered with the tensile strength and elongation. The results obtained in the writer's laboratory on sand cast ⅝-in. web bars are shown in Table 4.

Yield strengths at 0.1 per cent offset are always lower in manganese bronzes of this class than the yield strengths obtained at 0.5 per cent extension under load. The permanent sets accompanying these yields varied from 0.18 to 0.21 per cent, according to the copper content. Thus it will be seen that our 0.5 per cent yield strengths had a permanent set twice as large as the offset used in the paper, yet the yield strengths were about the same. Stress strain curves for these alloys often show a gradual curvature from the start and, at best, give a low proportional limit, which makes it difficult to obtain an accurate measure of the modulus. Moduli for our alloys were 14.5×10^6 psi. If moduli of lower values were used to determine the slope for the percentage offset, then higher yield strengths would be obtained.

Perhaps Ensign Robertson can clarify this situation.

Co-Chairman Thieme: I believe that Ensign Robertson has done a very good job in the time he has had to prepare the information. He has shown us that cartridge cases—rifle shells as we would call them in the industry—can be used. Fired cartridge cases are being used and have been used in quite large quantity. The proposition we have here of the utilization of materials is sometimes not entirely one of direct utilization. It becomes a matter of economics, a matter of costs or of production speeds. Sometimes we are able to accomplish things in laboratories with small heats of 50 or 100 lb. that can not possibly be approached when we come to production methods.

As to the effect of antimony on manganese bronze, the antimony content has never been a source of trouble in the 49B3e type of alloy. That is the alloy of 65,000 psi. tensile strength and 20 per cent elongation. But as we increase the tensile strength and as the alloys become a great deal harder to make, that is, containing higher iron, manganese and aluminum, the effect of the antimony becomes much more critical.

The percentage of antimony in fired rifle shells is of the order that practically any quantity of them can be used. However, it is a different story when we start to produce manganese bronze in ingot form or to utilize shells direct in the foundry, because the uniformity of the product can not be depended upon when rifle shells are used straight, that is, 100 per cent rifle shells. It is one thing to make a laboratory heat, as I said

[1] H. Kramer & Co., Chicago, Ill.

Table 4

YIELD STRENGTHS OF CAST MANGANESE BRONZE AT 0.5 PER CENT EXTENSION UNDER LOAD

Heat No.	Composition, per cent Cu	Sn	Fe	Al	Yield Strength, 0.5 per cent extension under load	Tensile Strength, psi.	Elongation, per cent in 2 in.
1	57.3	0.78	1.07	1.08	44,000	87,000	30.0
2	58.0	0.85	1.20	1.09	41,000	82,500	34.0
3	59.0	0.81	1.10	1.07	36,500	78,500	40.0

before, and another thing to make a production heat in which conditions can not be so fully under control as they are in a laboratory.

Does the 0.5 per cent of lead shown in Fig. 1 represent the lead content of the rifle shell?

ENSIGN ROBERTSON: The analysis that was shown in Fig. 1 does not mean that that is the percentage of lead that will be found throughout the case. That was done more or less for comparison and, actually, all we did was to take a dirty shell, saw it up and spark it right on the dirtiest surface we could find. We would vaporize whatever was there plus a little bit of the base metal. The reason we did that in the beginning was because we thought it would be just a cleaning problem, and we wanted to see what the results were before and after cleaning. That analysis of 0.5 per cent of lead just means that at the spot where we sparked it there was approximately that much lead around the surface and contained in the dirt. The actual lead content of remelted cases was found to be about 0.005 per cent.

CO-CHAIRMAN THIEME: The reason I ask that question is because I have never yet found 0.5 per cent of lead in any fired rifle shell, and we use 40,000 or 50,000 lb. a month in our plant.

We have found also that any grade of manganese bronze could be made with fired rifle shells excepting the very high-strength bronze, and that is something that has to be watched. Even there, we have been successful in making high-strength manganese bronze that would meet the 46B29 specification without the tin. When shells are used, our production speed drops as much as 25 per cent, and there are some heats that have to be thrown out. Perhaps the best way to utilize rifle shells is to use as many as we can.

WM. ROMANOFF[2]: If, in order to allow freer machinability, we add an element such as lead to manganese bronze, we usually increase our copper content to take care of the drop in elongation caused by the additional lead. I believe that that should have been done where the antimony content was high (Table 3) and you knew that the ductility was to drop. The copper content should have been raised to compensate for it.

ENSIGN ROBERTSON: We wanted to keep them all on the same basis as much as we could. Any variations from the nominal were not intentional.

MR. ROMANOFF: A variation from 57 to 58 per cent of copper would mean considerably less than one between 56 and 57 per cent. When you are down to 56 per cent of copper you are really at the danger point in elongation.

H. R. KING[3]: We pull manganese bronzes to the 49B3e specification that have 0.2

[2] H. Kramer & Co., Chicago, Ill.
[3] Metal & Alloy Specialties Co., Inc., Buffalo, N. Y.

per cent of lead and probably traces of antimony that we do not know about, and we regularly get 30 per cent elongation. There is another manganese bronze with 0.50 per cent of lead that pulls 15 per cent elongation on the normal test bar. I can bear out Mr. Romanoff that the small amounts of lead that we are discussing here will not affect the elongation to the extent of bringing it down to 4 or 6 per cent because these other manganese bronzes carry so much more lead and still have 15 per cent elongation.

B. A. MILLER[4]: Do Mr. Romanoff and Mr. King have in mind that the tin content would affect the elongation?

MR. KING: Yes. Our 49B3e manganese bronze has a low tin content, under 0.10 per cent.

MR. ROMANOFF: That would depend upon what alloy you are speaking of. If you are speaking of a free-machining leaded alloy, the A.S.T.M. specification calls for 60,000 psi. minimum tensile strength with 20 per cent elongation. Tin runs as high as one per cent, and the lead runs pretty close to one per cent. Still we are able to obtain 60,000 psi. tensile strength and 20 per cent elongation. With the lower lead content we naturally will get lower tin due to the alloying materials used, unless we intentionally add tin.

MEMBER: How do you account for the difference in yield strengths in heats E25 and E24A of Table 2?

ENSIGN ROBERTSON: A copper content of 57.86 per cent, with aluminum at 0.90 per cent, gave the higher yield strength, 40,000 psi. With a copper content of 58.91 per cent and aluminum at 0.68 per cent, the yield strength was 27,500 psi.

MEMBER: A yield strength of 40,000 psi. is hard to get, keeping below one per cent of aluminum.

MR. HALLIWELL: We have to bear in mind that the yield strengths shown in Table 2 are with 0.1 per cent offset. The high copper and low aluminum in heat E24A of Table 2 would give the low yield strength of 27,500 psi.

ENSIGN ROBERTSON: Bear in mind that the tin content was about 0.5 per cent.

G. H. BRADSHAW[5]: The Philadelphia Navy Yard has been using cartridge cases for the manufacture of manganese bronze and we did not seem to have any trouble. Our practice is that when we get high lead with high tin, we definitely make an attempt to keep the zinc content around 36 and 37 per cent and keep a Brinell hardness of 165 to 170 on the chill test mold. I believe that there will be no trouble with either tensile strength or elongation provided that the zinc content is reduced about 1½ per cent when there is high tin or lead.

CO-CHAIRMAN THIEME: The work of Halliwell* bears out what you say.

MR. BRADSHAW: The iron and manganese—which are in solution, not in suspension—must be closely controlled.

CO-CHAIRMAN THIEME: It is much more difficult to get the alloying constituents dissolved uniformly in low melting point 70/30 brass than it is when copper or a high melting point material is used.

ENSIGN ROBERTSON (*author's closure*): The author agrees with Mr. Thieme that the problem of using fired rifle shells is a matter of economics, costs and production speeds. However, it has been the purpose of this paper to show that from a chemical and metallurgical point of view, these rifle shells could be used as 100 per cent of the base charge in making manganese bronze to meet specifications 49B3e.

---

[4] Baldwin Locomotive Works, Cramp Brass & Iron Foundries Div., Philadelphia, Pa.

[5] Philadelphia Navy Yard, Philadelphia, Pa.

*Halliwell, G. P., "*The Effect of Lead on Some Mechanical Properties of Manganese Bronze*," TRANSACTIONS, American Foundrymen's Association, vol. 51, pp. 837-868 (1943).

In regard to the points raised by Mr. Romanoff and Mr. King about the low elongation found in heats E-11 and E-12 (Table 3), it should be noted that these low values are not caused by the lead alone, but by the relatively high antimony content of these heats. The author agrees with these gentlemen that 30 per cent elongation may be obtained with a lead content of 0.2 per cent, but only if the antimony content is well below 0.01 per cent.

In order to investigate the effect of adding lead to manganese bronze made from rifle shells, four additional heats were made and the results are shown in Table 5. The lead content was varied from 0.09 per cent to 0.23 per cent, and the antimony content was 0.003 per cent or less. The results show good tensile properties, and at least 29 per cent elongation in each heat. This data substantiates the statements of Mr. King and Mr. Romanoff, as well as those made by the author.

Table 5

EFFECT OF LEAD ON MECHANICAL PROPERTIES OF MANGANESE BRONZE MADE FROM CARTRIDGE CASES

Heat No.	Type of Case	Composition, per cent								Mechanical Properties	
		Cu	*Zn*	*Sn*	*Fe*	*Al*	*Mn*	*Pb*	*Sb*	*Tensile Strength, psi.*	*Elongation, Per Cent in 2 in.*
E 26	40 mm.	57.45	39.32	0.53	0.86	0.96	0.78	0.09	0.003	80,500	29.0
E 27	40 mm.	57.57	39.23	0.50	0.86	0.92	0.78	0.14	0.003	79,800	31.5
E 28	50 cal.	57.61	39.16	0.56	0.84	0.93	0.70	0.23	0.002	74,000	29.5
E 29	50 cal,	57.68	39.04	0.56	0.84	0.93	0.72	0.23	0.002	70,500	30.5

The author realizes that for this class of manganese bronze (with modulus of elasticity of 14.5×10^6), higher yield strengths will be obtained with 0.5 per cent extension under load than with 0.1 per cent offset, as pointed out by Mr. Halliwell.

Our alloys were tested on a hydraulic type testing machine equipped with an automatic recorder. A calculation of the modulus from these curves showed it to be somewhat lower than that used by Mr. Halliwell, thus accounting for the higher yield strengths.

The author wishes to express his appreciation to all those who participated in the discussion

Heat Treatment of Medium Carbon Cast Steel in Moderately Heavy Sections, Part II

By K. L. Clark*, H. F. Bishop* and H. F. Taylor*, Washington, D. C.

1. A paper of the same title, which appeared in the A.F.A. Transactions for March, 1944[1], shows results from physical tests made upon samples removed from various positions within 10x10x20-in. castings and from two types of test coupons. Five different heat treatments were employed to determine if there was any justification for the long period in the furnace which is required by a prolonged anneal sometimes specified for heat treating castings having compositions and section sizes similar to those investigated. Unrestricted heating rates, higher than usual temperatures of heating, abbreviated holding periods, and both water-quenching and normalizing with subsequent tempering treatments were tried as means of reducing "in-the-furnace" time. Results show that physical properties produced by the shorter treatments were equal to or, in most cases, better than those which were obtained from the annealed castings.

2. Since liquid quenching facilities are limited or overtaxed in many foundries, it was apparent that further work should be confined to normalizing treatments. Moreover, consideration of the limitations of batch heating and of the safety factor which is desirable in commercial heat treatment indicated that holding periods in the furnace of less than one hr. per in. of section should be avoided. Accordingly, six additional sets of castings and coupons, having a composition closely approximating that originally used (Table 1), were heat treated as shown by treatments seven through twelve of Table 2. These treatments were based upon normalizing from 1650° F.

Table 1

Composition of Steels Used

	Per Cent		
Elements	*Heat R*	*Heat S*	*Heat T*
Carbon	0.24	0.27	0.24
Manganese	0.66	0.63	0.56
Silicon	0.44	0.43	0.40
Sulphur	0.016	0.012	0.017
Phosphorus	0.031	0.030	0.036
Copper	0.21	0.17	0.15
Nickel	0.75	0.73	0.79
Chromium	0.22	0.19	0.15

*Steel Castings Section, Division of Physical Metallurgy, Naval Research Laboratory, Anacostia Station.

[1] Transactions, American Foundrymen's Association, vol. 51, pp. 617-646 (1943).

Table 2

HEAT TREATMENTS EMPLOYED

Steel Composition	Heat Treatment, no.	Heating Temp., °F.	Holding Time, hr.	Method of Cooling†	Reheating Temp., °F.	Holding Time, hr.	Method of Cooling†	Tempering Temp., °F.	Holding Time, hr.	Method of Cooling†	Approx. Total Time, hr.
R	1	1800	6	AC to 950	1650	3	AC to 900	1300	3	FC to 950 AC	36
R	2	1700	4½	AC to 900				1300	3	FC to 720 AC	32
R	3*	1600	25	FC to 865 AC							64
S	4	1800	5	AC to 750	1650	2	WQ	1230	4	AC	22
S	5	1800	2	AC to 750				1230	4	AC	13
S	6*	Same as No. 3									
T	7	1650	10	AC to 800				1250	10	AC	28
T	8	1650	2½	AC to 800				1250	2½	AC	13
T	9	1800	10	AC to 800	1650	10	AC to 800	1250	10	AC	43
T	10	2000	10	AC to 800	1650	10	AC to 800	1250	10	AC	44
T	11	1650	10	AC to 800	1650	10	AC to 800	1250	10	AC	42
T	12*	Same as No. 3									

NOTE: AC=Air Cooled; FC=Furnace Cooled; WQ=Water Quenched.

*Treatments 3, 6 and 12 were used as control treatments in which the heating time was 15 hr. and cooling time was 24 hr.; in all other treatments, the heating rate was approximately 400° F. per hr.

†Temperatures shown are in Degrees Fahrenheit.

(900° C.) after holding at temperature for one hr. per in. of section and tempering at 1250° F. (675° C.). Variations of the base treatment consisted of prior normalizing from 1650° F. (900° C.), 1800° F. (980° C.) and 2000° F. (1095° C.). A single normalizing and tempering treatment with holding times of one-fourth hr. per in. of section and a long annealing treatment were also included in the series for purposes of comparison.

3. Compositions, heat treatments, and physical property data which were previously published are reproduced in condensed form with corresponding data from the final set of castings for reference (Table 3). Specimens for

Table 3

Effects of Heat Treatments Upon Physical Properties in 10x10x20-in. Castings and Coupons

Heat	Heat Treat-ment, no.	Location of Sample	Tensile Strength, psi.	Yield Strength, psi.	Redn. of Area, per cent	Elong. in 2-in., per cent	Izod Impact, ft.-lb.	Cold Bend: Max. Load, lb.	Cold Bend: Angle of Bend, deg.
	1	Center	70,000	45,000	18.1	16.4	31.5	7,400	95
	1	Corner	76,000	49,000	35.8	26.8	30.0	7,600	95
	1	Coupon	76,000	50,500	57.4	32.4	35.0	7,900	135*
	2	Center	67,000	43,750	14.5	9.4	22.0	7,100	65
K	2	Corner	76,000	45,900	37.0	25.8	20.5	7,600	75
	2	Coupon	75,500	48,850	58.2	32.0	27.0	8,000	135*
	3	Center	68,000	40,500	18.1	10.9	32.0	7,400	75
	3	Corner	78,650	43,800	38.5	26.5	31.0	7,600	70
	3	Coupon	77,500	47,500	45.2	28.9	37.5	8,000	135*
	4	Center	77,250	50,650	21.0	13.0	51.0	7,750	71
	4	Corner	84,500	58,300	47.0	26.0	64.0	8,300	84
	4	Coupon	93,875	71,100	63.0	28.0	79.0	8,600	135*
	5	Center	72,500	41,900	20.0	15.0	40.0	7,350	63
S	5	Corner	80,250	47,600	31.0	23.0	32.0	7,550	66
	5	Coupon	79,750	48,250	55.0	30.0	33.0	8,000	135*
	6	Center	72,500	39,650	24.0	19.0	37.0	7,400	68
	6	Corner	79,350	45,200	31.0	20.0	27.0	7,800	70
	6	Coupon	79,375	44,500	44.0	27.0	30.0	8,100	135*
	7	Center	68,875	42,200	24.7	16.0	28.0	6,660	84
	7	Corner	72,415	44,000	36.7	25.1	31.0	7,030	77
	7	Coupon	72,690	44,000	57.5	31.7	34.8	7,505	135*
	8	Center	67,460	44,500	20.7	12.8	34.8	7,080	85
	8	Corner	74,585	41,625	34.3	23.9	36.0	7,305	115
	8	Coupon	74,050	46,250	57.6	30.5	41.5	7,455	135*
	9	Center	67,170	45,960	23.2	13.1	37.1	7,120	83
	9	Corner	72,585	44,625	39.2	28.0	32.3	7,245	97
T	9	Coupon	72,810	47,750	59.9	31.5	42.0	7,525	135*
	10	Center	66,750	45,500	19.9	13.6	34.8	6,950	94
	10	Corner	72,420	43,670	33.1	26.5	33.3	7,185	121
	10	Coupon	71,875	45,940	59.4	31.0	39.3	7,240	135*
	11	Center	66,375	42,875	21.5	14.8	40.9	7,085	94
	11	Corner	71,875	46,040	36.3	24.6	35.0	7,235	135*
	11	Coupon	73,190	49,190	60.7	31.8	42.0	7,470	135*
	12	Center	65,165	37,915	19.8	11.4	38.0	6,975	75
	12	Corner	71,665	39,625	32.7	24.8	35.3	7,740	107
	12	Coupon	73,060	41,625	50.5	29.2	38.3	7,530	135*

*Upper limit used.

obtaining these data were removed longitudinally from the 10x10x20-in. castings or from the Type *B* coupon, both described in the original paper. The so-called Type *B* coupon consists of a group of 1x1½x5-in. specimen blanks, cast vertically around, and with one side of each blank adjoining a heavy section upon which is imposed an open riser.

4. Physical properties resulting from Treatment No. 7, the single normalizing and tempering treatment, follow very closely in most respects those obtained from other treatments of the same series. When this fact is considered in conjunction with reduced furnace time requirements and lessened scaling of castings as compared to the long annealing treatment or the double treatments, and lowered maintenance and operating costs as compared to the higher temperature treatments, it is believed that the single normalizing and tempering treatment generally offers the best advantages for the type of casting involved.

ACKNOWLEDGMENT

The authors wish to acknowledge their indebtedness to the Navy Department for sponsoring the work.

Die Casting Aluminum Alloys by the Cold Chamber Process

By S. U. Siena*, Little Neck, N. Y.

Abstract

The cold chamber, or high pressure, die casting process has received considerable impetus since the entrance of the United States into the war. This impetus has resulted from the development of aluminum alloys primarily adapted to the process. In this paper, the author discusses not only the alloys used, but the details of the process and makes recommendations to be observed to secure the best possible product. He discusses both casting and die design and the factors involved in the process, such as die preheating, die coatings, metal injection speeds and pressures, metal and die temperature control and melting practice. Proper inspection to secure the best possible product is emphasized.

1. The cold chamber process of die casting, otherwise known as "high pressure die casting process," has come into its own during the past few years and has become a very important manufacturing process in our War Effort. By the proper use of the cold chamber die casting process, much machining of parts can be eliminated and a considerable decrease in weight and materials used can be obtained.

2. Vast improvements have been made by the die casting industry in the past 2 or 3 years toward improving the quality of their product, and the further improvement of quality has been deemed so important that the War Production Board has set up a committee to certify certain die casters to be equipped for, and capable of the manufacture of, first quality castings.

3. This paper is based on actual experience and past observations in the hope that it will be of some help to designers and users of die castings and perhaps of some use to those who are new in the industry.

Alloys Used

4. Originally, most aluminum die castings were made of an alloy containing 4 per cent copper, 5 per cent silicon and remainder aluminum, with either relatively low or high impurities. This alloy worked out very well for low-

*Die Casting Coordinator, Sperry Gyroscope Co., Inc.

Note: This paper was presented at an Aluminum and Magnesium Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 27, 1944.

pressure, gooseneck type machines. However, for the cold chamber process, better casting alloys were required. An alloy containing 13 per cent silicon and remainder aluminum was used in early high-preassure castings. Recently, better casting alloys have been developed. About a year ago, an alloy of 9 per cent silicon, 3½ per cent copper and remainder aluminum was standardized for most ordnance work.

5. An alloy containing 10 per cent silicon, 0.5 per cent magnesium and remainder aluminum, recently has been used and is claimed to be an excellent casting alloy. For castings requiring the highest combination of strength and ductility, an alloy of 8 per cent magnesium and remainder substantially aluminum has been standardized at the sacrifice of some castability. As there is some iron pick-up in the die casting process, most specifications have allowed maximum iron of 1.3 per cent.

DIE CASTING DESIGN

6. To facilitate ease of casting layout and machining, die castings should be designed with the parting line all in one plane. Undercuts should be eliminated wherever possible to prevent intricate coring and loose pieces in the die. Designs should be made using dimensional tolerances of ±0.0025-in. for the first inch and ±0.0015-in. for each additional inch or fraction thereof, except where wider tolerances are satisfactory. In certain cases where design requirements make it necessary, closer tolerances may be obtained at the cost of more painstaking die work and inspection.

Wall Thickness

7. In the die casting process, it is difficult to obtain heavy sections free from porosity. Optimum wall thickness should be between 3/64 and 5/32-in. To strive to keep within these tolerances, surfaces should be left unmachined wherever possible. On surfaces that must be machined, a machining allowance of not greater than 0.020-in. per side should be allowed. Bosses having holes in the finished part should be cored for casting. To facilitate ejection and removal from the die, a taper of 0.010-in. per in. per side should be used. Large, complex castings should be broken down into smaller sub-assemblies wherever possible. Inserts of wrought material can be cast in place, an example being sleeves in pump housings. External threads, not exceeding 24 pitch, can be cast up to a class 2 fit.

DIE DESIGN

8. Dies can be made which have one or more cavities of the same or different parts. In this respect, it may be noted that the highest quality casting can be made from a single cavity die, since the maximum control can be maintained on the pressure, the velocity, and the temperature at which the metal

enters the cavity. In many cases, the machine available for specific castings can not be operated economically with a single cavity die. Therefore, multi-cavity dies are used at the sacrifice of some control over the quality of the product.

Die Components

9. The die consists of two halves, a cover and ejector half and the ejection mechanism. The cover half of the die is fastened to the stationary platen of the machine. The ejector half of the die is fastened to the ejector box, which in turn is fastened to the movable platen of the machine. The actuating medium for opening and closing the die may be either hydraulic or mechanical. The gate passage in the die for entrance of metal into the cavity should be as straight and free from obstructions as possible. The size should be in proportion to the cavity which is to be filled, and the length of this passageway should be kept to a minimum.

Venting

10. Vents must be cut in the die about the cavity in relation with the gate in such manner as to permit the air in the cavity to exit when the molten metal is forced into the cavity. Otherwise, air will be trapped in the cavity and cause a porous casting. Larger overflow vents often are necessary in the die, usually at the farthest point in the cavity from the gate, to allow the first metal entering the die to overflow and carry with it most of the dross and lubricating medium that is forced ahead of the molten metal.

Die Steels

11. The die should be operated at the highest possible temperature. Consequently, the best grades of heat resistant steel should be used. A steel containing one per cent tungsten, 5 per cent chromium, 1.5 per cent molybdenum, 0.35 per cent carbon, heat treated to a hardness of about 450 Brinell, has been found to be satisfactory. On small cores where breakage is sometimes excessive, an 18-4-1 high speed steel has been used successfully.

12. Cheaply made hobbed dies, case carburized, have proved most unsatisfactory for high pressure aluminum castings, since they become heat checked sometimes after only a few hundred castings have been made.

CASTING OPERATION

13. Die temperature should be controlled closely. This is very important. Maximum die temperature allowable is restricted by the steels available to withstand the temperatures and pressures encountered. Normal good practice, at this time, is to use a die temperature of from 400 to 500° F. Higher die temperatures would be consistent with the production of better quality castings

and may be used when better die steels are available. The use of higher temperatures will cause the operation to be slower.

Die Coatings

14. Die coatings are necessary to reduce initial chill and prevent alloying of the die casting metal with the die. A spray made of chalk water or colloidal graphite and either water or a light oil has been found to be best. Some form of die lubricant also must be used. Both colloidal graphite and light oil act as good lubrication media. Melted paraffin or beeswax can be used as a lubricant when sprayed on the die between shots, and heavy graphitic greases are best for the lubrication of ejector pins, and the plunger tip. To keep the injector plunger operating freely in the sleeve, it must be water cooled.

Injection Speed and Applied Pressure

15. There are many combinations of speed of injection and applied pressure that can be used in a die casting operation. Both of these factors are exceedingly important in controlling porosity in the die casting. A high injection rate is required on castings having a wall thickness under 3/64-in. The disadvantage of high injection rates is that spraying of metal occurs in the cavity. The spraying action of the metal against the cavity tends to erode the steel, and causes the formation of oxides which decrease fluidity. The oxides and viscous metal are trapped in the cavity, causing porosity.

16. If the castings have been so designed as to maintain uniform wall thicknesses between 3/64 and 5/32-in., then slower injection rates may be used. In this case, the metal flows into the cavity with a minimum amount of turbulence and the oxides and other non-metallics are carried ahead of the stream of molten metal through the cavity and into the overflow vents. The pressure used must be sufficiently high to cause the metal to flow uniformly through all parts of the cavity and into the vents before it starts to freeze and also to compress the metal in the die to prevent cavities resulting from liquid to solid shrinkage.

Pressures Used

17. In general, high pressures will decrease the amount of porosity present in a die casting but high pressure is not a panacea for porosity. The plunger tip, by which the pressure is applied to the molten metal, is actuated hydraulically. Pressure on the metal of from 5,000 to 30,000 psi. is used in the cold chamber process. Newest machines are designed to give controlled plunger speeds of 9 to 15-in. per sec. and to develop the high pressures previously noted at the end of the stroke. Once sound castings are obtained from a given combination of speed and pressure, the equipment must be so constructed as to make possible the maintenance of these conditions throughout the run.

18. It is very important that machines be equipped with pressure gauges. It also is essential that constant die temperatures be maintained throughout a run. This is controlled by the careful preheating of the die at the start of a run and thereafter, by the uniformity of the time interval between shots and by the rate at which cooling water is passed through the die.

Importance of Temperature Control

19. Automatic temperature control of the metal in the holding pot is very important. If too low a temperature is used and the metal is cast in the mushy state, the segregation of beta iron silicide will result in hard spots in the castings. Hard spots resulting from this practice can cause no end of trouble in machining operations. Metal in the holding pot should be maintained molten and at a constant temperature at all times. The reason for this is that the fluidity of the metal and the rate of solidification will vary as temperature varies. Once a cycle is established that gives sound castings, it is important that all conditions relative to this cycle be maintained under constant conditions, and the temperature of the metal in the holding pot is one of these conditions.

20. Care should be taken to find the exact weight of metal required for a shot and then to give the operator a ladle having the proper volume to hold exactly this amount of metal.

Melting Practice

21. Two types of melting facilities currently are used for aluminum. In some shops, small ingots of aluminum of the proper alloy are fed into the holding pot from time to time and enough heat is supplied to the holding pot to melt the metal as it is added and to maintain constant temperature of the molten aluminum. In other shops, all of the melting of cold metal is done in a separate furnace and molten metal is supplied to the holding pots at the machine. The author feels that better control of temperature can be maintained by the latter method.

22. Both iron and refractory pots are used. If iron pots are used, they must be removed from the furnace and given a good coating of lime, or other similar material, at frequent intervals, otherwise the iron pick-up by the metal will be excessive. No iron pick-up is encountered from the melting pot if refractory crucibles are used, so it is felt that refractory crucibles are preferable in holding pots.

INSPECTION OF CASTINGS

23. It has been stressed previously in this paper that it is important to maintain constant conditions throughout a die casting run, so that the quality of the product can be maintained. Before the proper set of conditions can be ascertained, it is necessary to have adequate inspection means to determine

whether a good casting is being produced. X-ray inspection is a most important means of determining this. After the die has been hardened and sufficient castings have been made to determine proper mechanical operation of the die, a few castings should be made and the conditions under which they are made recorded. These castings should then be x-rayed through all their sections. If porosity is revealed at a point where it would be detrimental in the fabrication or to the use of the casting, some of the conditions under which the casting was made should be changed, one at a time, until sound castings are obtained, as revealed by x-ray examination.

24. X-ray fluoroscopy is now being used as a means of x-ray inspection where 100 per cent inspection of parts is required. It has been the author's experience that fluoroscopy can be a useful tool to separate a mixed lot of good and bad castings. However, fluoroscopic inspection of first parts can never replace radiographic inspection, as the fluoroscopic examination will not reveal all defects. When fluoroscopy is used, radiographic negatives should be made first, and then the conditions under which the fluoroscope is used should

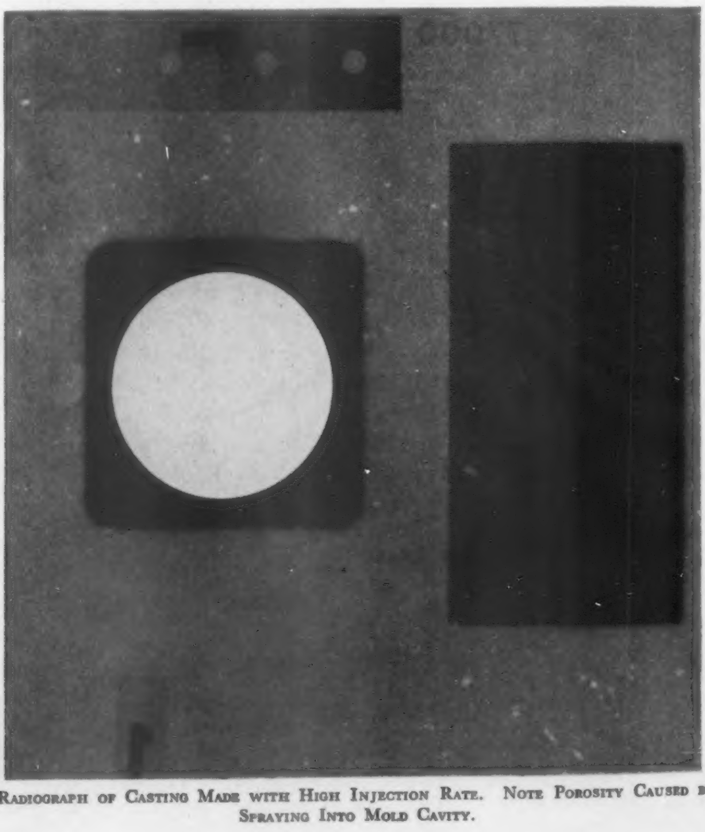


FIG. 1—RADIOGRAPH OF CASTING MADE WITH HIGH INJECTION RATE. NOTE POROSITY CAUSED BY METAL SPRAYING INTO MOLD CAVITY.

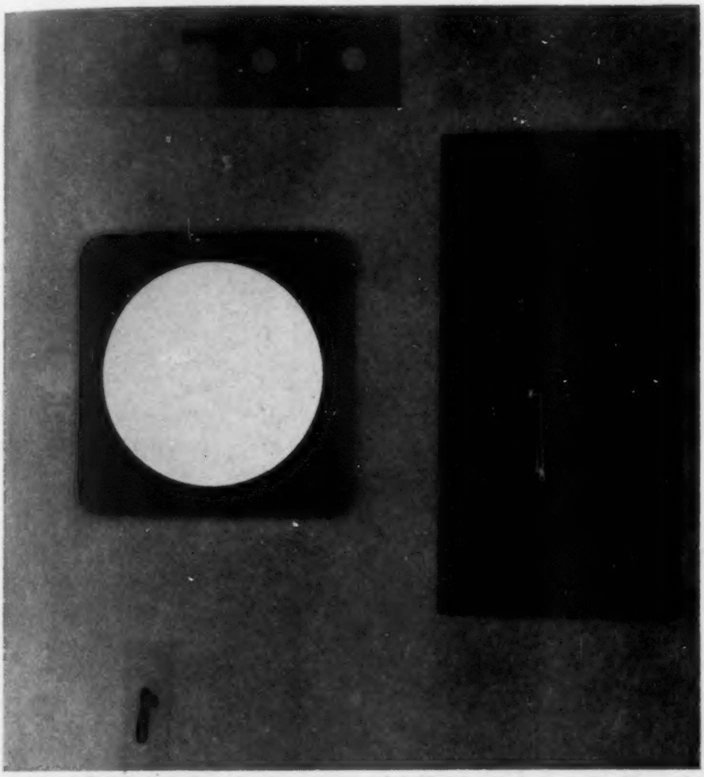


FIG. 2—RADIOGRAPH MADE OF CASTING OF SAME DESIGN BUT MADE UNDER VERY HIGH PRESSURE WITH SLOW INJECTION RATE. NOTE ABSENCE OF POROSITY.

be so varied as to reveal defects which are known to be present in castings and previously located on radiographic negatives.

25. Figure 1 is a radiograph of a casting which had been made with a high rate of injection, resulting in a spraying action which caused the porosity revealed by x-ray. Figure 2 is a radiograph of the same part made with very high pressure. In this case, the injection rate was slow, resulting in a uniform, porosity-free product.

SUMMARY

26. Summarizing the facts regarding the cold chamber die casting process, it may be stated that:

1. The high pressure die casting process can be used to make sound, high strength, inexpensive parts to close dimensions. To use this process to its greatest advantage, the designer of parts should be familiar with die casting merits and limitations and should design his parts accordingly.

2. Die design should be based on single cavities wherever possible, the shortest possible gates, and sufficient vents and overflows to permit (a) the venting of the air from the mold and (b) the overflow of dross from the cavity.

3. Slow enough speeds of injection should be used to prevent spraying action of the metal in the cavity, and sufficient pressure should be used to prevent porosity resulting from liquid to solid shrinkage.

4. First castings in a run should be inspected to determine that a satisfactory product is obtained and then, constant conditions of operation maintained throughout the run.

ACKNOWLEDGEMENT

27. Acknowledgment is herewith made to the Materials Laboratory, Sperry Gyroscope Co., Inc., for its assistance in the preparation of this paper.

DISCUSSION

Presiding: L. BROWN, Magnesium Fabricators Div., Bohn Aluminum & Brass Corp., Adrian, Mich.

Co-Chairman: J. C. Fox, Doehler Die Casting Co., Toledo, Ohio.

J. J. BAUM[1]: What method do you use to degassify the metal prior to its entrance into the ladle?

MR. SIENA: We try to maintain the metal in the holding pot with as little agitation as possible. We have had no experience in otherwise degassifying the metal in the holding pot.

P. D. FROST[2]: How close are the tolerances and what is the reproducibility?

MR. SIENA: Generally, the standard practice is for a tolerance of 0.0025 in. per in. for the first in., and 0.0015 in. for each additional in. or fraction thereof. This is true in aluminum and magnesium practice. However, there are conditions where a spread of holes may have to be held to closer tolerances and, by trial and error, these closer tolerances can be achieved.

K. PHILLIPS[3]: To what tolerances are the dies made? The 0.0025 in. per in. is the variation in the casting itself.

MR. SIENA: In designing and building a die, the designer utilizes, in aluminum and magnesium, approximately 0.0055 to 0.006 in. per in. shrinkage. Therefore, the die includes the shrinkage factors. However, it is not always possible to guess the complete shrinkage on a die casting and, therefore, it may be necessary to rework the impression or possibly to respace hole locations in order to achieve the closer tolerances.

R. L. BERLIN[4]: Assuming optimum casting conditions and satisfactory design, what percentage of regular production run of castings should we expect to be free of gas holes?

[1] Allison Div., General Motors Corp., Indianapolis, Ind.
[2] Curtis Wright Corp., Buffalo, N. Y.
[3] Briggs Mfg. Co., Cleveland, Ohio.
[4] Wright Aeronautical Corp., Lockland, Ohio.

MR. SIENA: In actual operation, castings have been produced with a scrap loss of 7 per cent.

A. SUGAR[5]: Is the porous condition actually gas porosity, or is it due to air trapped in an improperly vented die cavity?

MR. SIENA: Most of the porosity is due to the air which is trapped in the impression or ahead of the metal which enters the mold. However, the lubricating media, which we know contains volatile material, can also create gas.

MR. SUGAR: Volatilized lubricant would result in a scrap casting.

MR. SIENA: Not necessarily; not if we vent through the impression and the gas appears on the surface of the castings. There are two types of porosity, and possibly the porosity which appears on the casting surface should not even be called that. There are three types of defects that might be cause for rejection of a casting. One type would be internal porosity, the second shrinkage, and the third type is an apparent chill mark or laminated appearance on the outer surface, also known as surface porosity.

MR. SUGAR: Your shrinkage, then, is not a gas porosity?

MR. SIENA: No.

MR. SUGAR: Your greatest percentages of rejections are for shrinkage, for gas porosity, or for entrapped air, or would you differentiate between the three?

MR. SIENA: I would differentiate between the three and I would not say that any one of them would be the biggest single factor in scrapping castings. I would say every one of those elements would be entirely dependent upon the way the castings had been originally designed.

MR. SUGAR: What has casting design to do with gas porosity? A casting is certainly not designed for a definite amount of gas in the metal.

MR. SIENA: That is very true.

MR. SUGAR: So, in reality, this defect is not gas porosity. It is either microshrinkage, or it is due to die cavity air that is not being properly vented. As soon as the casting design gets to be a factor, then it certainly can not be due to gas already in the metal when it goes into the cold chamber.

MR. SIENA: But casting design is a factor and, because most designers neglect its importance, the foundry industry suffers from the defects caused either by shrinkage or porosity.

[5] U. S. Metals Refining Co., New York, N. Y.

Pulverized Coal Firing of Malleable Iron Annealing Kilns

By L. S. Wilcoxson*, New York, and D. F. Sawtelle**, Branford, Conn.

Abstract

This paper is an account of the use of pulverized coal as a fuel in malleable iron annealing kilns. First, by direct firing an old hand-fired kiln, followed by the conventional pair of car type periodic kilns fired alternately with one pulverizer; and the more recent installation of a direct-fired circulating system with which any or all of the five kilns can be fired from one pulverizer.

General

1. Pulverized coal was used for both melting and annealing in the malleable iron industry as early as 1919 in both the direct-firing and circulating systems. In 1925, the foundry with which the author is connected, purchased a high-speed beater-type pulverizer for pulverizing charcoal for use in mold facing, with the idea of adapting the pulverizer to the firing of one of a series of hand-fired annealing kilns.

2. In 1926, a second pulverizer of this same type was installed and put in successful operation, melting iron in a batch-type air furnace. This was followed in 1927 with a similar pulverizer, installed for firing a second batch-type air furnace.

3. From the experience gained from the successful operation of these two pulverizers on the melting furnaces, work progressed on firing one of the ten hand-fired kilns with pulverized coal.

4. After raising the roof of the kiln to provide better gas circulation, changing the flue system within the kiln to obtain proper heat distribution, and insulating the side walls, this kiln was put in successful operation during 1929, and, with many changes and new parts in the pulverizer, has been in constant use since that time.

5. As to the interest malleable foundrymen have in the use of pulverized coal, it is only necessary to refer to the paper presented before the A.F.A. convention in 1942, by Bean and Jaeschke[1]. Table 2 in that paper, giving comparative cost figures on oil-fired, hand-coal-fired, and pulverized-coal-fired annealing kilns is most informative, and explains why, as is shown in Table 3, 45.7 per cent of the annual tonnage of malleable iron produced is annealed with pulverized coal. The first pair of periodic car type pulverized-

*Executive Assistant, The Babcock & Wilson Co., New York, N. Y.
**Metallurgist, Malleable Iron Fittings Co., Branford, Conn.
[1] Bean, W. R., and Jaeschke, W. R., "*Periodic Malleable Annealing Furnaces,*" Transactions, American Foundrymen's Association, vol. 50, pp. 39-49 (1942).
Note: This paper was presented at a Malleable Iron Founding Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 26, 1944.

coal-fired kilns, as described in this paper, was put in operation during 1933.

6. In 1940, a second pair of periodic car-type annealing kilns was put in operation, having several features which were incorporated in their construction and which were considered to have advantages over the conventional type. A much greater use of insulating brick was made, and the roof was slanted up toward the burner end to afford more combustion space where most needed and to provide for better gas circulation.

Pulverizer

7. A different type of pulverizer, using a series of steel balls instead of beaters and traveling at less than one-sixth the shaft speed of the pulverizers previously used, was installed with these new kilns. Both kilns and pulverizer on subsequent operations have justified their selection. There have since been lower fuel costs due to better kiln insulation; improved combustion due to the consistently high degree of fineness of the pulverized coal and uniform air-to-coal ratio throughout the entire heating cycle; and lower maintenance costs due to low speed and the grinding principle employed in this pulverizer. A representative proximate coal analysis and screen analysis of the pulverized coal are shown in Table 1.

Pulverized Coal Systems

8. There are three types of pulverized-coal systems now available, any one of which may be employed, depending upon surrounding circumstances, and which, in chronological order of development are:

(1) Storage or bin system.
(2) Direct-fired unit system.
(3) Direct-fired circulating system.

Table 1

Coal Analysis and Pulverized Coal Fineness

Components		*Per Cent*
Moisture	Air dry loss at 95° F.	3.9
	Total	5.8
Volatile matter		21.8
Fixed carbon		72.8
Ash		5.4
Sulphur		0.9
B.t.u. per lb., dry		14,900
Fineness, Passing Screen No.		
50		100.0
100		99.6
140		98.8
200		94.0
325		85.5

Storage System

9. The storage system is the earliest form of application of pulverized-coal firing, and involves a pulverizer plant operating under essentially base-load conditions for a sufficient number of hours per day to supply pulverized coal to storage bins in a quantity sufficient to meet the plant's daily requirements. The pulverized coal normally is fed from a storage bin adjacent to the pulverizers, by means of an air transport system, to smaller individual storage bins adjacent the burners to which the coal is to be supplied. From these storage bins the coal is fed by means of a feeder into a stream of primary air and the mixture delivered to the burners, by which, with the addition of secondary air, combustion is attained in the kiln. Such installations have been made, and are still in operation, on a number of annealing kilns and melting furnaces in the malleable industry.

10. This system has the disadvantage of high initial capital expenditure for the necessary equipment involved, and high overall operating cost. There is, as well, an operating disadvantage in that the pulverized coal, on being separated from its stream of carrier air when delivered to the storage bins, is apt to pack and snowball, and thus interfere not only with combustion efficiency, but also with the control of the process to which heat is applied. It has a further disadvantage in that the raw coal must be predried in a separately fired dryer, or in the pulverizer with preheated air, and the air must be vented to the atmosphere through a system of dust eliminating devices. It has been largely superseded in recent applications of pulverized-coal firing by the direct-firing system, which, with its modified circulating system, forms the basis of the present discussion.

Direct-Fired System

11. In the direct-fired system of pulverized-coal firing, the burner lines are taken directly from the pulverizer, so that the air used through the pulverizer to pick up the coal pulverized therein constitutes the primary air for combustion, and secondary air from another source is added at the burners to complete combustion. The great advantage of the direct-fired system is its simplicity and the minimum of equipment involved, as compared with the storage system previously referred to, as well as the ability, in direct firing, to keep particles of finely pulverized coal separated, from the point of pulverization to the point of use, by its continued suspension in air.

12. However, this system is limited in its most advantageous application to one pulverizer heating one kiln at a time, and the control for more or less fuel is effected by changing the rate of input to the pulverizer. In other words, in order to control the B.t.u. requirement to a kiln it is necessary to heat that kiln by an individual pulverizer, regardless of heat requirement. A further requirement, of course, is that there must be a space available adjacent to the kilns being fired for the installation of the pulverizer with its drive, fan, raw-coal bin, and raw-coal handling equipment.

Direct-Fired Circulating System

13. A direct-fired circulating system has been developed more recently to meet those conditions outside the zone of economic application of the direct-fired system, while at the same time maintaining the advantages of a direct-fired system. These conditions, incidentally, are particularly prevalent in the malleable iron industry, consisting of large numbers of small annealing kilns having small individual heat requirements, and often so spaced that there is considerable distance between the furthermost kilns of a group. Very frequently such kilns are of such a nature as to their installation and use that there is no space available in their immediate vicinity for the installation of a pulverizer and its appurtenant equipment.

14. To meet these conditions, the direct-fired circulating system has been developed so that the pipe carrying the pulverized coal and its primary air is in the form of a continuous loop, arranged so that the loop extends adjacent to the kilns to be fired, and also to some convenient location away from the kilns where the pulverizer and its component equipment can be installed as an integral part of the loop, and yet avoid any interference with operation of the kilns. The loop can be of any length up to 1000 ft., or more, and as many burner lines can be taken from it as there are burners to feed, with a low limit on individual burner capacity for general purposes of less than 50 lb. of coal per hr.

Coal and Air Feed

15. Each burner can be turned on and off as required. Coal feed to the pulverizer is automatically controlled, so that a mixture of pulverized coal and air in proper proportions is supplied to the continuous loop at the same rate at which it is fed to the burners at any particular moment, thus resulting in the maintenance of a substantially constant pulverized coal and air supply in the circulating line.

16. Figure 1 illustrates diagrammatically the layout of a direct-firing circulating system, from which the relationship of the pulverizer to the circulating system can be clearly seen. The ease and flexibility of operation of such a

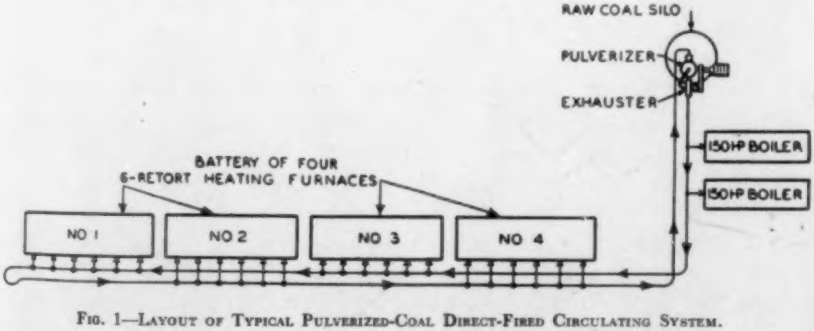


FIG. 1—LAYOUT OF TYPICAL PULVERIZED-COAL DIRECT-FIRED CIRCULATING SYSTEM.

circulating system is best illustrated by the fact that its operation and performance is closely analogous to that when gas is used as a fuel.

17. Figure 2 shows an interesting development in connection with pulverized-coal firing of some malleable annealing kilns. There are 11 annealing kilns located in one room, six of these kilns being indicated in the three arrangements, *A, B* and *C* of Fig. 2. The arrangement shown by *A* represents the original installation of direct-firing pulverized coal equipment, in which a single pulverizer was employed to direct-fire two annealing kilns, firing only one kiln at a time.

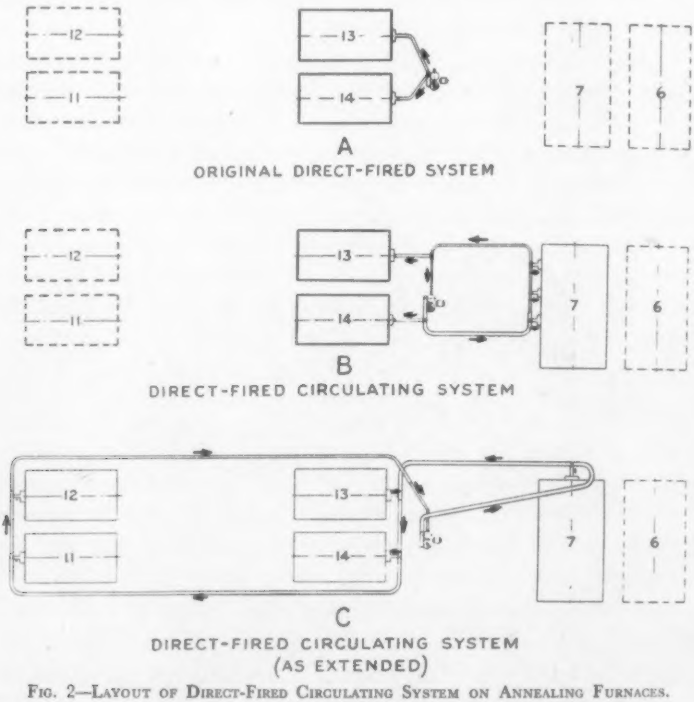


FIG. 2—LAYOUT OF DIRECT-FIRED CIRCULATING SYSTEM ON ANNEALING FURNACES.

Kiln Capacity and Heating Cycle

18. Each of these kilns has a capacity of approximately 15 tons of malleable iron castings per heat, the heating cycle being 76 hr. and the period between the cycles also being 76 hr., so that by staggering the heating and cooling periods of the two kilns, the pulverizer was operated essentially continuously. The pulverizer has a rated capacity, with coal having a grindability of 70, of 830 lb. per hr. at a fineness of 85 per cent through 200 mesh, while it actually supplied the heating requirements of the kiln, which amounted to 300 lb. of coal per hr., with pulverized coal having a fineness of 95 per cent through 200 mesh. In this installation, it was possible to locate the pulverizer

close to and about equi-distant between the kilns to be fired, resulting in simple and short burner lines between the pulverizer and the kilns.

19. With the obvious over-capacity available in the pulverizer, as indicated by the figures given, the original direct-fired arrangement involving the two annealing kilns was converted to a direct-fired circulating system. An additional annealing kiln, having approximately twice the capacity of either of the two kilns already being fired, was added to the system and supplied with coal from the same pulverizer installation. The layout of this direct-fired circulating system is shown in Fig. 2-*B*.

20. In making this conversion, the larger kiln was converted from hand firing to pulverized-coal firing by the addition of a single burner and a Dutch oven. Furthermore, the floor of the furnace near the burner was lowered 6 in. and the flue outlets were changed to provide better gas circulation and alleviate over-heating the top of pots adjacent to the firing wall. The results were gratifying, in that the time of the heating cycle was drastically reduced, with a reduction in the amount of coal required to anneal a charge of malleable castings, as shown by Table 2.

Time-Temperature Relationship

21. The time-temperature relationship for both hand firing and pulverized-coal firing is illustrated in Fig. 3. It would be possible to obtain a decidedly higher fuel ratio on this kiln with pulverized-coal firing at some sacrifice in the time saved on the heating cycle, but, with the existing plant requirements, the importance of increased production with moderate fuel economy takes precedence. It will be noted that, as against a firing period of 195 hr. with hand firing and a fuel ratio of 2.7 tons of castings per ton of coal, with pulverized coal the firing period was reduced to 87 hr., with an improved fuel ratio of 3.1 tons of castings per ton of coal. With this firing arrangement, any combination of furnace operating cycles was satisfactorily handled.

22. Subsequently, this direct-fired circulating system was further extended, as shown by Fig. 2-*C*, to incorporate two additional annealing kilns, each having a capacity equivalent to the original direct-fired kilns, and this system has been in satisfactory operation since December, 1942. The pulverizer is of the same type as used for the original direct-fired installation, although the

Table 2

Annealing Cycle and Average Iron-to-Coal Ratio During 40-Day Period

Type Kilns	*Method of Firing*	*Average Weight of Charge, tons*	*Average Time Under Fire, hr.*	*Iron-to-Coal Ratio*
Batch	Hand Fired	30	195	2.7
Batch	Pulverized-Coal Circulating	30	119	3.5
Car	Pulverized-Coal Direct-Fired	15	78	4.2
Car	Pulverized-Coal Circulating	15	67	4.1

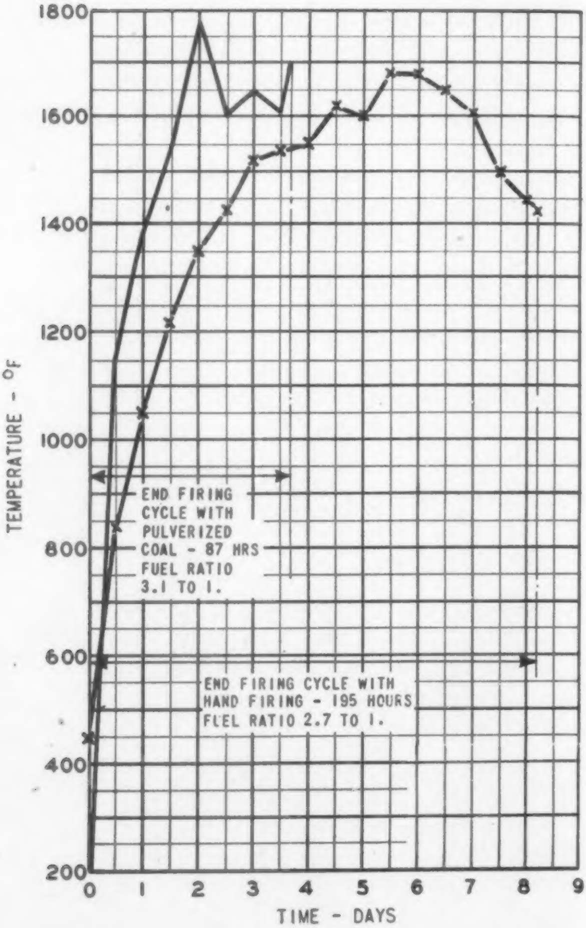


FIG. 3—TIME-TEMPERATURE RELATIONSHIP—HAND FIRING AND PULVERIZED COAL FIRING OF MALLEABLE IRON ANNEALING FURNACES. FURNACE CAPACITY—30 TONS OF CASTINGS.

fan was modified to give a greater static pressure to overcome the increased resistance in the extended circulating line, and a larger motor was installed.

23. As staggering of the heating and cooling periods of the five kilns being fired by this circulating system is desirable from the standpoint of normal economical operation of the plant, the five kilns are seldom, if ever, at the maximum firing rate at the same time, and, consequently, any normal combination of kiln heating cycles can be satisfactorily handled.

24. In this specific application, the maximum temperature to be attained in the annealing pots is in the neighborhood of 1700° F., so that the maximum kiln temperature is in the neighborhood of 1800 to 1900° F. With these temperature conditions, it is possible to burn a large variety of coals available at

minimum cost, these coals being such that the ash deposited in the kiln from the pulverized coal being burned is in dry condition and is removed readily between heats.

Firing Costs

25. This installation of direct-fired circulating system of pulverized-coal firing has proved to be very satisfactory, as is indicated by the cost comparison shown in Table 3.

26. As a result of the economical operation indicated in Table 3, a second circulating system to fire the remaining six annealing kilns is now being installed. This additional installation is shown in Fig. 4.

27. One of the outstanding features of the direct-fired circulating system is the elimination of numerous small coal piles adjacent each kiln in the annealing room, and the maintenance of a single coal pile in some convenient, accessible location adjacent to the pulverizer supplying pulverized coal and air to the circulating system. Another important feature is the provision of greater flexibility and more dependable control than is obtainable with either hand firing or an individual direct-firing system, due to the ability to regulate burner performance directly from the constant-density coal and air mixture in the circulating line.

28. Since pulverization is accomplished in a high temperature atmosphere and the coal is in continuous circulation over the entire operating range of the system, it is possible to handle high-moisture coal without impairing the quality of the performance. Preheated air may be supplied from a steam air heater, from a separately fired heater, or by inducing hot gases from the kiln flue through the pulverizer and tempering with cold air to the desired temperature.

29. Consistent high fineness and uniform air-to-coal ratio through the

Table 3

COMPARATIVE FIRING COSTS FOR MALLEABLE ANNEALING KILNS*

	Firing Method		
	Hand Fired	*Pulverized-Coal Direct-Firing*	*Pulverized-Coal Direct-Firing Circul. System*
Fuel cost per ton	$7.50	$7.50	$7.50
Coal consumption per ton of castings, lb.	740	480	490
Fuel cost	$2.77	$1.79	$1.83
Labor cost	1.25	1.07	1.07
Power cost	....	0.17	0.19
Maintenance	....	0.02	0.02
Total firing cost*	4.02	3.05	3.11

*Cost per net ton of castings annealed.

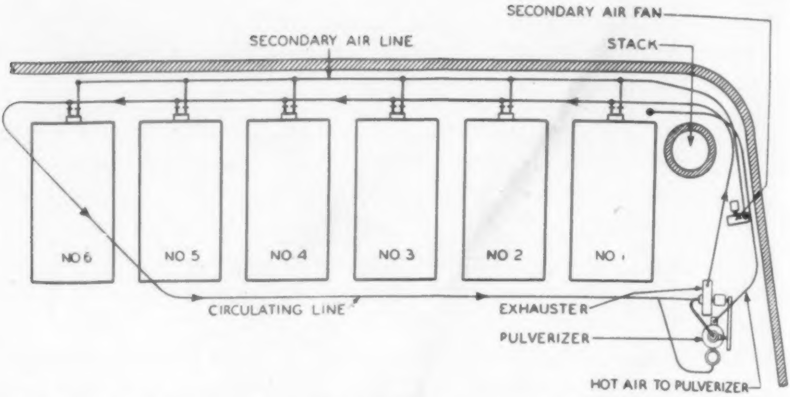


FIG. 4—LAYOUT OF PULVERIZED-COAL DIRECT-FIRED CIRCULATING SYSTEM ON MALLEABLE HEATING FURNACES.

system, together with proper design of the distributing system, make it unnecessary to provide special take-off valves in order to obtain proper distribution of coal to various burners. The system is so designed that the minimum velocity through the line at any point in the system is high enough to insure against coal settling in the line, thus maintaining a uniform density throughout the system.

DISCUSSION

Presiding: A. M. FULTON, Northern Malleable Iron Co., St. Paul, Minn.

Co-Chairman: FRED L. WOLF, Ross Tacony Crucible Co., Tacony, Philadelphia, Pa.

H. E. LEICKLY[1]: When you were taking your different costs to compare pulverized fuel firing against hand firing, did you use approximately the same coal total in your annealing ovens at that 1750° F. temperature in hand firing that you did in pulverized fuel firing?

MR. SAWTELLE: No, we were never able to get the temperature of the hand-fired kilns up to the temperatures that we used in firing pulverized coal. In hand firing, the temperatures were at least 100 or 150° F. lower. We were depending on natural draft and could not do it.

MR. LEICKLY: What was the difference in the cost of the pots, which really enters into this?

MR. SAWTELLE: That comes out about even. The cycle is much shorter and the number of heats per pot greater with pulverized fuels. We get about 16 heats per pot, on the average, but the pots are in longer in the hand-fired kilns and they do not come up to so high a temperature. They are not in so long in the case of the pulverized-fuel-fired kilns but come up to the higher temperature, and it seems to even out.

J. DOERFNER[2]: Do you make any attempt to control the moisture of the coal going to your pulverizer and does it affect the quality of your products?

MR. WILCOXSON: No. With this type of pulverizer, you can use coal that has a considerable quantity of moisture in it. As an actual experience, we have pulverized coal with a moisture content of up to 17 or 18 per cent, perfectly satisfactory, by using hot air from an air heater for the pulverizer.

W. D. MCMILLAN[3]: The fuel cost of $7.50 per ton is after pulverizing?

MR. WILCOXSON: No, that is just the cost of the raw coal. The power cost, labor and maintenance are the three items that go to make up the cost of pulverization. The maintenance, of course, is the replacement of the rings, the balls and the wearing parts of the pulverizer.

E. M. STRICK[4]: At the operating temperature of 1750° F., does that mean the temperature inside the pots?

MR. SAWTELLE: That is right. Inside the top pot, we go as high as 1800° F., and we try to get the bottom pots up to 1700° F., so we call it an average of 1750° F.

MR. STRICK: And you have not noticed any appreciable increase in pot cost at these temperatures from that of 1600° F. hand firing?

MR. SAWTELLE: Some of our pots are in the hand-fired kilns two, three or four times as long as they are in the pulverized-coal-fired kilns and it seems to even up.

R. F. GREENE[5]: It so happens that we have used that type of pulverizer for about 7 years, operating on two 30-ton malleable furnaces, with very good success. We find an extremely low maintenance, and, as far as temperatures are concerned, it is possible to turn out about 3000° F. most any time. Moisture does not seem to affect it. We use the steam preheaters to start and then take hot air off the stack later. The pulverization seems to be pretty good. But I would like to ask, is this mill powered sufficiently so

[1] Fanner Mfg. Co., Cleveland, Ohio.
[2] Gunite Foundries Corp., Rockford, Ill.
[3] International Harvester Co., McCormick Works, Chicago.
[4] Erie Malleable Iron Co., Erie, Pa.
[5] Detroit Brass & Malleable Works, Wyandotte, Mich.

that in case of a power shutdown, where the mill stops, when the power comes back on, will the mill take up the load without cleaning it out?

MR. WILCOXSON: Generally speaking, yes. I think that to some extent that depends upon what the operation was at the time the mill went down, but, under normal operation, it generally will take care of such a situation as that.

MR. GREENE: We do not find that to be the case. We do not give our heats enough time for a possible power shutdown, which, incidentally, does not often happen. However, if we are down for 10 or 15 min. and we can not make up the time, then it is a question of overtime for about 60 men, and that is serious.

MR. WILCOXSON: In your particular case, you have direct firing and not the circulating system. With the circulating system, you are on the line practically continuously and all of the regulation is done by the burners at the furnace rather than by manipulating the pulverizer. As far as a shutdown of this type of pulverizer is concerned, if the feeder controller had been feeding at a high rate just prior to the power shutdown, there might have been a considerable quantity of coal in the mill. That might make it more difficult to start up.

MR. GREENE: The feeder control has to supply, and keep at a constant level, a certain quantity of coal in the mill, which we will assume is at that level during all the operation. Ours are set for short cycles, and we are able to keep the flame at a pretty constant level. That is about the only thing I would like to have cleared up on that.

C. C. LAWSON[6]: The statement was made that it took 2 or 2½ times as long under the hand-firing system as it did under the pulverized-coal-firing system. I can not understand why, with a raise in temperature of only 100 to 150 degrees, it should take twice as long to anneal under hand-firing as it does under the higher temperature. It was said that pot life was saved by reason of the shorter annealing cycle. At the high temperature, at 1600 or 1650° F. with the old cycle, against 1700 or 1800° F. with the new cycle, it seems to me that doubling the time, or 2½ times the time, is too much.

MR. SAWTELLE: In the old annealing kilns there were seven in a line on one stack and the fire boxes in the corner had very little draft and we were entirely dependent on weather conditions as to whether an annealing kiln would come up in one week or two weeks. With pulverized-fuel kilns, we certainly have a great advantage in getting them up at the proper time.

MR. LAWSON: We are talking about pot life.

MR. SAWTELLE: We have burned pots in the corners of a hand-fired kiln, when there was very poor circulation, before we could ever get the center of that kiln up to sufficient temperature. Taking tests on a great number of pots, over a long period of time, and alternating them top and bottom or whenever they might be located, we can not find any difference in pot life in the old hand-fireds or in the quicker pulverized-fuel-fired kilns.

There may be another reason for that. With the extremely fine pulverization of coal, we carry a very smoky atmosphere, and that may have quite a lot to do with how much the pots scale under pulverized firing.

MR. WILCOXSON: I would like to add a thought at this point. The last statement is a very pertinent one. With pulverized coal, one can regulate the atmosphere in the furnace very readily.

AUBREY GRINDLE[7]: I can add a little light on this problem of the pot life and the length of time with pulverized coal and hand firing. With pulverized coal, we can force the oven up to temperature, get circulation in the oven and, therefore, get the bottoms

[6] Wagner Malleable Iron Co., Decatur, Ill.

[7] Whiting Corp., Harvey, Ill.

up in much quicker time than we can when we are depending entirely on natural draft for circulation.

M. E. McKinney[8]: I might offer some light on the question of time for annealing or time for soaking. When we get up to temperatures of 1600 and 1700° F., a drop of 100 degrees will easily increase the time by half if not more. It is very drastic above 1600° F.

Mr. Wilcoxson: I think the curve showed, too, that the increase of temperature with the pulverized coal is on a very much steeper gradient than it is in the case of hand firing.

Mr. Strick: What kind of packing do you use in the pots fired at 1750° F.?

Mr. Sawtelle: Sand blast gravel. We also try to screen out all of the pot scale. If the pot scale content goes too high in the sand blast gravel, the pots will stick together at those temperatures, but they shake out quite freely, getting over 1800° F. on the top pots.

Chairman Fulton: What is the mesh of the sand blast gravel used?

Mr. Sawtelle: I do not know the mesh, but it is about as large as my little finger nail.

D. Levinson[9]: Has anyone ever done anything in the way of metallizing of pots to increase the life?

Co-Chairman Wolf: Some years ago I had an experience with annealing pots which had been metallized with aluminum applied by means of the metal spray gun. The expense involved in using the metal spray was not justified by the slight increase in the life of the pot.

Mr. Levinson: I believe there is a metal spray on the market that withstands temperatures up to 1800° F. The claim is made for it that it will increase the pot life by 400 per cent.

Co-Chairman Wolf: We ran a pot one time with a spray of aluminum. We did get a short increase in pot life, but not very much.

C. F. Joseph[10]: We sprayed some aluminum on some pots at one time, but it did not seem to help. We tried to duplicate the calorizing effect. Then we had some pots made by adding aluminum to the steel, and that did not seem to give us any longer life. As far as the steel pots are concerned, they will last longer than the cast iron pots. I mean that the steel pots with the aluminum added to them did not seem to last longer than the regular steel pots.

Co-Chairman Wolf: I had some pots calorized and I did get a slight increase in life, but not enough to justify the expense involved. I also tried out some high chrome-nickel steel pots and they were fine. The cost, however, was prohibitive.

---

[8] International Harvester Co., Ltd., Hamilton, Ontario, Canada.
[9] Acme Steel & Malleable Iron Works, Buffalo, N. Y.
[10] Saginaw Malleable Iron Co., Saginaw, Mich.

Training Foremen on the Job

By Frank K. Dossett*, Cleveland, Ohio

Introduction

1. Volumes have been written on foremanship training, and speeches and magazine articles constantly are being produced on this increasingly important theme. It is obvious, therefore, that the limitations of such a paper as this permit only a general presentation of the subject.

2. Comparatively few industries followed any comprehensive plan of foremanship training before the United States entered the war, but the "Training Within Industry" program of the War Manpower Commission has given industrial concerns, great and small, the benefit of enlarged vision. The fact that no man can do better than he knows has been impressed upon industry with renewed emphasis. We have been brought to realize that adequate instruction must precede efficient performance.

The Purpose of the Training

3. The purpose of this type of training is to better equip the foreman to perform his important part in the progress of a nation that is becoming more and more industrialized, and in which the worker's undeniable right to a "voice in his work place" is being constantly emphasized. The foreman's job is essentially a job of management. By virtue of his position, he is, for all practical purposes, the manager of a small business enterprise. He is given money, machines, material, and men—and whether his group numbers 20 or 200, the principles involved are fundamentally the same. The difference is simply one of degree, because the problems that he must solve are identical with those which confront the divisional superintendent or the general manager.

4. For many years, industry has sought to impress upon its foremen that their primary responsibility was "to get the work out," while maintaining the proper relation between quality and quantity and with a minimum waste of material. This fact is still true but, in the past decade, American business has come to realize that there are many other factors involved in manufacturing, and that among these, the human equation is of primary importance.

5. It goes without saying that the foreman must get his work done through people. It is imperative, therefore, that he understand, now as never before, the basic laws of human psychology which underlie man's emotional reactions.

---

*Director of Supervisory Training, Thompson Products, Inc.
Note: This paper was presented at a Foreman Training Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 25, 1944.

He must know how to relate himself to his workmen, not as a boss, but as a leader and counsellor, and he must understand the technique of keeping his workers properly related to one another. All this involves information and inspiration that cannot be secured apart from a well-devised "on the job" training program.

6. We often have heard it said—"To the worker, the foreman is the company." This is unquestionably true. Within his group, he is not only the actual manager, but is, in many instances, the only member of management with whom the worker has an intimate contact. His attitudes and his actions, therefore, are interpreted by the worker as reflecting the spirit and policy of the company.

The Scope of the Training

7. The question naturally arises—what is the legitimate scope of foremanship training, and to what degree should it be carried on? In the very nature of the case, the answer to this question must be determined by the peculiar circumstances with which the particular industry is confronted. It is impossible to present a comprehensive program that would be applicable to every business. Whatever standards are set up must permit of change and adaptation to meet local conditions. However, in broad outline, all the members of supervisory personnel must be trained as an integral part of management in understanding the fundamental principles upon which American industry is built, as well as their specific production problems.

8. Primarily, of course, the foreman must possess a complete knowledge of the tools and equipment with which his group works. He must be an expert in performance—his hand as well as his head must be trained. Only through comprehensive job knowledge can he retain the respect and admiration of the men who work with him. Workmen like to look up to their "boss." He must be the man who "knows, and knows that he knows."

Company Policies.

9. In addition to a knowledge of the materials and equipment with which his men work, his understanding must include an intelligent grasp of the company policies which constitute the organizational structure, and of the government regulations under which he must operate. Not only that, but the foreman also must become cost conscious in respect to the relation between his particular unit and the operation of the company as a whole. He must realize that loss through unnecessary waste of material or labor in any department may lead to bankruptcy of the whole enterprise—that the inefficiency of any particular group, however small, might become the leak that ultimately would sink the ship. It is quite impossible, therefore, to overestimate the importance of the intellectual and practical training of the foreman on the job.

10. Any adequate program of training must enable the foreman to meet the requirements of the new age in which we live. It is an emotional age in which the emphasis is being placed more and more upon human values. The personalities and feelings of workers are of increasing importance. Life, for all of us, is largely a matter of emphasis, and industry has always involved money, machines, material and men.

11. There was a time when the emphasis was placed upon the monetary return resulting from the efficient use of machines and materials. It is no secret that, in the "good old days," human labor was regarded somewhat as a commodity to be bought and sold in the open market. But we have come to a new and better day and, interestingly enough, we have discovered that by placing the emphasis where it rightfully belongs—upon the human factor—not only is life made more enjoyable for everyone, but greater profits accrue to the organization.

12. By way of recapitulation, let us stress the fact that any comprehensive program of training must provide the foreman with a clear understanding of the following basic factors:

(1) The technical "know how" required for the particular job.
(2) The scope of the responsibilities connected with the job.
(3) The relative position of all members of supervision, as indicated on an organization chart.
(4) The relation of manufacturing to all other essential phases of the enterprise.
(5) The company policies and practices which are set by top management.
(6) The governmental regulations under which industry must operate.
(7) The complex human factors involved in the efficient handling of industrial manpower.

METHODS OF TRAINING

13. It is one thing to appreciate what must be done, but quite another thing to determine how to do it. Experience has shown that several methods have proved effective in the training of men. We can learn much from the way they have been trained in schools and colleges to take their places in the social, political, business, and professional life of the nation, and we can draw other practical lessons from their training for military service. No one exclusive method is superior to all others, but the best program of foremanship training is a combination of all the methods that have proved valuable in other lines of human progress. Four basic training techniques are worthy of consideration.

Conference Method.

14. The conference method, where small groups of foremen gather for the informal consideration of particular problems that are of mutual and immediate concern. The program must be flexible enough to permit the introduction of any particular subject while it is "hot." Physical facilities should be provided on company property and should be of the very best. Poorly lighted and inadequately ventilated basement or "out-of-the-way" meeting rooms discount the importance of the effort and tend to diminish the interest of the group.

15. As a general rule, discussion groups should be composed of men with relatively equal authority. Insofar as it is possible, divisional superintendents, general foremen, line foremen and supervisors should not be mixed in any one discussion group. By and large, supervisors will attend meetings and participate with enthusiasm only in the measure in which they feel that the things being discussed can be related to their own immediate needs. The more tangible and non-related the subject, the more difficult it is to maintain regular attendance—and forced attendance defeats its own purpose.

16. Suitable conference leaders must be provided either by securing the services of professional teachers from outside sources or by developing members within the organization to meet this requirement. In the larger companies, where there is an educational director properly positioned as a member of the general staff, intensive courses in conference leadership are arranged under his guidance. This makes available members of the organization, who have natural leadership qualities, to direct the discussion groups.

Lecture Conference Method.

17. The lecture conference method, which consists of the presentation of subjects of general interest, followed by a discussion period in which individual members of the group are encouraged to participate. These conferences should be presided over by a capable leader and addressed by a qualified speaker. The programs should be arranged in series, with a logical sequence and a definite end aim in view, and might profitably include such subjects as economics, sociology, psychology and government. Questions of compnay policy, public concern, or of special interest to the group, should be given ample consideration.

18. In any well-rounded program, this basic training should be supplemented by a series of meetings led by department heads, who review the functioning of their particular departments. These have a tremendous value in the development of inter-departmental cooperation. It is a truism that, only in the measure in which all members of supervision understand the importance of the activities of their fellow executives, are they tolerant and cooperative.

19. Meetings should be held on company time, and be considered as a

part of the regular responsibilities of the forman. If, for any reason, this seems to be inadvisable, then he should be paid for time thus spent outside of his regular working hours.

Mass Meeting

20. The mass meeting, which should include all members of supervision in one great meeting, or series of meetings, held monthly or quarterly. These assemblies are less deliberative and more inspirational, and have a distinct value in creating an atmosphere, developing an organizational consciousness, and deepening morale. There is a decided emotional value in such fraternal gatherings, and religious and political leaders, throughout the centuries, have found them indispensable.

21. The mass meeting can be made a tremendous asset to industry in the development of understanding, loyalty and teamwork. These meetings should have a definite objective. They are not merely for entertainment, but are intended primarily for instruction and inspiration, and should be planned carefully so as to enable the foreman to get a better overall picture of the entire enterprise.

22. Such meetings are invaluable when addressed by members of top management, or outside speakers who are capable of bringing a stimulating message on the fundamentals of our "American Way of Life," what free enterprise means to the individual citizen, and other subjects related to the interests of the foreman. Their enjoyment can be greatly enhanced by holding the meetings amid pleasant surroundings with good music, and a hearty dinner provided by the company.

Written Messages

23. The judicious and regular use of the written word, devoted to foremanship problems. A steady flow of foremen's bulletins, dealing with pertinent questions as they arise in the shop, have great value when effectively employed. Letters containing information about company finances or anticipating changes in fundamental procedures, together with an occasional personalized communication from some member of top management, are equally valuable. Furthermore, a section in the plant publication reserved for supervisory education presents a possible medium for foremanship training which is overlooked all too often.

24. This entire field of the written message should be more widely explored by management because it is one of the most valuable methods of influencing the thinking of foremen and supervisors.

25. We need to remember that workers in the shop are essentially the same individuals after they ring their time cards as they were when they left their homes, and this is equally true of the foremen who supervise them. We must rid ourselves of the notion that there is a distinct shop psychology. We

hear a lot of talk about "shop language," but, as a matter of fact, it is not essentially different from that spoken by the same men when they are outside the shop. It may include a greater proportion of "cuss" words and vulgarisms, but even that is changing rapidly as industry recruits its workers from more widely divergent segments of the population, and as popular education raises the general intellectual standards.

Educational Level

26. There has been a tremendous upward movement in the educational level of all the American people since the turn of the century. At that time, there were about 600,000 young people in the high schools of America, while 40 years later, there were more than 6,600,000.

27. In the old days, lads entered our factories before they had finished grade school, but now they are practically all high school graduates, and a large number of them have had college training. The workers in our plants are regular readers of good books and magazines, as well as of others that are not so good, but, by and large, they represent a fair cross section of the American public as a whole. If foremen are to keep pace with this upward movement in the general educational level of the men whom they supervise, it is imperative that they be trained while on the job so that they may retain the respect and confidence of their workmen.

DIFFICULTIES IN TRAINING

28. The chief difficulty that stands in the way of supervisory training is found in the failure of top management to fully appreciate and adequately support the program. Unless the highest ranking executives of an organization are sold thoroughly on the importance of an educational program, it never can be entirely successful. Strange as it may seem, some members of upper management simply tolerate training programs. They regard them as temporary interruptions in the main business of the industry, and are looking forward to the time when they will be no longer bothered with the trouble and expense involved.

29. Other members of management do not wholeheartedly accept the idea of training, but endure it because they think it is expedient, even though their hearts are not in it. Unless we can develop, through all grades of management, a genuine appreciation of the practical value of informative and inspirational programs of foremanship training, industry will be handicapped in its development and progress.

Industrial Education

30. The inability to interpret the value of education in terms of specific and immediate returns, financial or otherwise, is another one of the difficulties

that lie in the way of industrial training. Someone has said that "men are simply boys grown tall," and this is nowhere more evident than among some of the higher executives in industry. Their attitude toward education is much the same as that of many lads in our high schools, who see no reason why they should continue their educational preparation, but are eager to get out and work so as to enable them to jingle more dollars in their pockets today.

31. Any program of education is a long-term effort. The returns are rarely immediate, but, like the farmer who invests his seed corn in the soil and waits for the harvest, so industry must plant and cultivate and patiently wait for the returns upon its investment in education and training.

32. Something of this same impatience, on the part of the foremen themselves, constitutes another hurdle that training is required to take. Some foremen expect immediate promotion when they have completed even a single training course. There is a persistant feeling, on the part of many members of supervision, that promotions are secured through "pull" rather than merit. Unfortunately, this has been all too true in the past, but as industry educates and trains its workers, the advancement of qualified employees to managerial positions becomes more and more the rule, and promotion through "pull" becomes less and less frequent.

33. The idea that individual progress depends rather "upon whom you know, than what you know," is gradually becoming uprooted, and workers are learning that, in the long run, progress depends upon individual merit. The overall picture of American industry proves this point beyond question for, as a matter of fact, most members of top management today have come up through the ranks "the hard way."

34. Another difficulty that stands in the way of foremanship training is found in the natural indifference and indolence of human nature — the tendency to be satisfied with things as they are — the old-timer's reluctance to give up the comfortable way of doing things and to accept a new and better way. "The good has always been the enemy of the best."

35. A further difficulty is really a combination of problems that have more or less common characteristics, such as the grouping of supervisory personnel of varying levels of authority, the combining of men with dissimilar motivations, and the inclusion of too many members in the discussion conferences.

36. The final major difficulty is likewise a combination of obstacles such as the natural tensions that characterize periods of war—the multiplicity of duties; the inevitable fatigue and frustration caused by long hours of work; the problems of transportation resulting from gasoline and tire rationing; the fear of immediate induction into the armed forces; and the feeling of futility regarding the future.

CONCLUSION

37. However, none of the difficulties that lie in the path of training are

insurmountable. They simply constitute a challenge to the intelligence and initiative of forward-looking and courageous industrial leaders. The results of training formen on the job cannot be overestimated, although they never can be fully tabulated. Nevertheless, the increased efficiency, which accompanies a well-planned and faithfully-executed training program, definitely reflects itself in the balance sheet of the company.

38. One of the great lessons industry has learned in the prosecution of the war, is that the training of foremen "on the job" is the most effective means of securing increased production. We have had it impressed upon us repeatedly that workers must think straight about their country, their company, their job, their fellow workers, and themselves, if they are to function effectively in competitive enterprise.

39. It also goes without question that the general morale of the worker is much higher when he knows that his foreman is qualified for the job by adequate training. Furthermore, the companies that have regular training programs find available for their needs, well-trained executives to fill the higher ranks of management as the occasion may require.

40. Progressive leaders of American industry never will be willing to return to the old hit-or-miss methods of supervisory training that characterized former years. Education and practical "on the job" training of foremen have come to industry to stay. In view of the trend of the times, it is logical to prophesy that, in the future, only those industries which put the emphasis upon human values will be able to survive in a complex and competitive society of free men.

Training Foremen to Handle Women

By W. J. Hebard*, East Chicago, Ind.

Introduction

1. In attempting to discuss such a subject as this, it is necessary for us to realize that each of us is at a different point with respect to the matter of employing women in foundries. Some of you undoubtedly have had a great deal more experience than the rest of us, and would be much better qualified to lead this discussion. Some of you, perhaps, are just getting under way, and some may just now be finding it necessary or desirable to start. These remarks, therefore, are to be considered only as an attempt to evoke a general discussion from which all of us may benefit.

2. It seems necessary to determine at the outset what information or skill needs to be conveyed to the supervisors, and then to consider the timing. It is the same familiar story of what is to be taught, when it should be taught, where it should be taught. Obviously, the supervisor should get what he needs *before* he has occasion to need it.

3. About a year ago, we received a call from the training director in a neighboring plant, the management of which had just made the decision that women were to be put into shop jobs. The foremen in the plant had become panicky at the announcement. No women ever before had worked in their shop, and the foremen did not know what they were going to do. Certainly, they didn't know anything about "handling women"—how were they supposed to treat them?

4. We had had some women in our plant, and the training director asked if he might bring some of his foremen over just to talk with the foremen in our plant who had been supervising the women. He felt that if he just could get his foremen to realize that other foremen actually had lived through the harrowing experience of supervising women, they might be reassured.

5. To make a long story short, they came, they saw, and they were reassured. They went back and spent some time getting acquainted with their new problem.

6. Right now, that firm has many more women employees than we have, and their foremen are certainly getting along no worse than foremen in other plants.

7. In this case, and we are sure that it is not unusual, the first teaching job was to convince those foremen that they were fundamentally qualified for the new task ahead of them.

---

*Personnel Director, Continental Roll and Steel Foundry Co.

Note: This paper was presented at a Foreman Training Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 25, 1944.

8. In other words, the first and perhaps the greatest problem in getting foremen to handle women employees for the first time, is to make them realize that *they* can do it—not some other foreman in some other kind of work, in some other plant, but your foremen, in their departments, in your plant.

Training Conferences

9. The foremen who are to handle women generally are brought together for conferences on such topics as:

(1) The analysis of present jobs suitable for women.
(2) The breaking down of present jobs, parts of which will be suitable for women.
(3) The training program to be arranged for each occupation or group of related occupations.
(4) Methods of getting women started in each department.
(5) Comparisons with other plants in the area and in the industry.
(6) Special problems in dealing with women, etc.

10. These topics, it will be noted, are not matters which are to be left entirely to the foreman. Rather, the conferences will draw out the experience of the foreman to help in the breaking down of jobs, the planning of training programs and the like, while at the same time they will serve to quicken his interest, put him on his toes and convince him that top management is ready to back him up.

11. It must be made clear that this is no "spur-of-the-moment" notion, but a carefully thought-through program of major importance. And here, it might be well to mention one of the drawbacks to a successful program of putting women into the shop. Too often, top management will tend to discourage the fullest utilization of women by disparaging remarks about the program.

12. No one is particularly happy about losing our regular manpower sources because of military service or because of better pay and easier work in some other plant, but that is just one of the sad facts which we must face during a war. We *must* use women, so we should try to get the best possible results out of them, and we can not do this if we spend our time thinking about how nice it will be when the war is over and we can get rid of them.

Pamphlets

13. The use of pamphlets on the special problems of handling women has proved quite successful. This is particularly true where the individual in charge of the training hesitates to pose as an "expert" himself and wants to get over some ideas by indirection. We would hesitate to say directly to a

foreman that he must never lose his head over a pretty girl who might be assigned to his department, and yet the warning can be made to sink in through the use of some of the general pamphlets which are available. Films, too, are available, although it is unfortunate that the foundry generally is slighted when any type of training film is planned.

Accidents

14. Perhaps the most satisfactory thing about a training program involving women is the fact that foremen will be more than anxious to prevent accidents to women employees. The emphasis on correct job instruction, with stress on safe work habits, can not be too great in breaking-in women. If we can get our foremen to realize that women usually are better than men at retaining habits, we can drive home the value of good job instruction.

Personnel Problems

15. In one way or another, firms employing women have made arrangements for capable handling of special personnel problems by some kind of counselling service. In some plants, women personnel officers are appointed to handle women applicants for employment, arrange for placement, oversee adjustment to the shop, and to handle the many little problems that affect women employees. In other plants, women counsellors are appointed, something like a dean of women in a college, who hear all of the personal difficulties of their charges and make adjustments wherever possible.

16. Still other plants, including several foundries with which we are acquainted, have employed so-called matrons who take care of a group of women employees in a particular department or on a given shift. In most cases, regardless of the title given to such women, they have no line authority, but are intended to help the line supervisors by acting as intermediaries.

Foremen and Counsellors

17. Whatever the plan may be, it should be made clear to the foreman. The value of such counsellors will be in direct relation to the manner in which they can be brought into close contact and harmony with the foremen. And foremen must be made to realize the importance of making proper use of such assistants.

18. During the early stages of women on the job, it has been found desirable to have conferences of the foremen involved to exchange experiences and to discuss mutual problems. These meetings need not be long and should be held about a week apart, at first, tapering off as the program settles down and is accepted as routine. Later, only occasional meetings need be held as follow-up, just to keep the foremen alert and "on the beam."

19. One of the problems likely to be encountered at this stage of the program is over-confidence. If the foremen first approach the problem "in fear and trembling"—any they usually do—it is likewise true that after they discover that the job is not nearly so horrible as they had expected, they are inclined to think that they must be pretty good. We have heard foremen with 2 or 3 weeks of experience in handling women talk as though they were experts—knowing all the answers. If this sort of thing does happen, it is advisable for the training director to do a little work. While the best approach must be decided for each individual case, perhaps a little study of cost, production, turnover and absentee figures will help to point out to the foreman the need for further improvement, and hence the need for further study of the job.

Wage Rates

20. As the program gets under way, another problem is encountered that requires an intelligent and fair approach on the part of the foreman. While there usually is a definite company policy with regard to wage rates, the administration of that policy depends largely on him. Difficulties in this respect vary widely. The general principle, as announced by the Secretary of Labor, the War Labor Board and other interested parties, has been "equal pay for equal work." This has been augmented by the corollary statement of "proportionate pay for proportionate work." It is in the application of these basic principles that foremen are apt to need assistance.

21. We recall one case in which a foreman, fully convinced of the superiority of men over women, had arrived at the conclusion that women on a certain job were not able to do as much as men on the same job, and had set up a differential—at least in his own mind—of almost 30 per cent between the rates to be paid the women and the rates to be paid men. After going through a breakdown of the job rather fully, he agreed that there was just one real difference—women could not lift the heavier pieces that sometimes came to the bench, and needed help in lifting. Going a bit further, he admitted that some men working on the same job, because of size or physical disabilities, needed the same help in lifting.

22. In the other direction, but just as serious, is the case of the foreman who had set up some tests as minimum standards for certain job classifications. These tests did not take into account quantity of work, need for special help in doing the job, attendance, attitude and all of the many factors which add up in the appraisal of an employee. But, when the women employees passed these tests, this foreman moved them ahead to the higher brackets. He was certainly a "good fellow" with the women, but the reaction came later from the men when they realized that they were expected to do much more actual work—at the same rate paid to the women.

23. Somewhere between these two lies the right answer. It is no less

serious to rate women too low than to rate them too high. The effect on both the women and their men co-workers must be considered carefully.

CONCLUSION

24. The foundry industry still offers a fertile field for the proper utilization of "womanpower." With the immediate future pointing toward even greater drafting of men, with no appreciable curtailment of the critical labor shortage, and with foundry occupations still the relatively undesirable occupations for newcomers, our aim must be to keep constantly alert to latest developments, to use all possible techniques in intelligently putting women to work and to "sell" always that something—call it romance if you will—which makes real foundrymen. We have in foundry management, from foreman to president, the brains to do the job well. It remains only for some one to direct those brains in the proper direction so that we may continue to be proud of the contribution which our industry is making in winning the war.

Women as Foremen

By S. M. Brah*, Baltimore, Md.

Introduction

1. Management, forced to consider the use of women as foremen due to manpower shortages, resulting from abnormal losses of personnel to other industries, high turnover and selective service, may safely consider the use of women as supervisors, based on the history and success of women in this capacity in many industries. Tradition and chivalry have proved to be a handicap in the use of women as supervisors in heavy industry, but a review of history should inspire top management in making use of those natural leadership characteristics possessed by the so-called weaker sex.

2. Helen of Troy, Joan of Arc, Catherine the Great of Russia, Mary, Queen of Scots, and Queen Victoria, to name only a few of the outstanding rulers of empires, stand as conclusive proof of the capacity of women to cope with the problems of leadership. There is plenty of room for individuality in practicing the art of being a boss, and the problem of using women as leaders in industry resolves itself into finding the right person.

Women Leaders in Industry

3. From time to time we find the names of women in the personnel columns of trade journals, in all management capacities, from president on down, in nearly every type of manufacturing and commercial enterprise.

4. The use of women as supervisors is not new and dates back to the earliest production manufacturing attempted in America. The textile industry is probably the forerunner of modern manufacturing in this country, and there are records of women as overseers in textile plants throughout New England as early as 1787.

Coreroom Foreman

5. Probably everyone present remembers, as a boy, working in some establishment where a woman was the boss. An illustration of this, with which we are personally acquainted, occurred in a large malleable iron foundry, where a woman was the general forelady of the coreroom for a period of about 25 years. The exact date of her employment is not known, but she was appointed forelady of the girl coremakers about 1908 and, in about 1916 or 1917, she was given complete charge of the coreroom, handling both men and women.

---

*Training Adviser, Rustless Iron and Steel Corp.

Note: This paper was presented at a Foreman Training Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 25, 1944.

6. The responsibilities of this job entailed the entire operations of the coreroom, from the mixing of the sand with binders to delivering cores to the molders. Naturally, there were some places where she required counsel and help, and we recall that this plant was one of the first in the country to use core blowing equipment. She needed the assistance of the mechanical experts in working out the "bugs" during the early days when this machinery was installed.

7. We remember her as a very forceful person, extremely anxious to keep her work on schedule and, above all else, she was a wonderful housekeeper. Anyone, man or woman, would have found it a pleasure to work in this coreroom, for it was a masterpiece of orderliness in every respect. All in all, she measured up to what could be expected of a first-class man, because the core operations of this foundry, when running to capacity, was a full-sized job for anyone. In about 1940, this lady was pensioned, and it can be said without reservation that she had well earned this privilege.

Women in Foundries

8. The last World War found many women working in foundries, particularly in the repetitive type production foundries, and there probably was no phase of foundry work that was not done with women. The present war has found larger numbers of women employed in all of the countries at war. The technical and trade journals have brought us stories of the major contributions to the production efforts of Russia, England and the United States. The record of the Training Within Industry Division of the War Manpower Commission shows that over 187,000 women have been trained as supervisors.

SUPERVISORY REQUIREMENTS

9. Supervisory requirements for any job may be condensed into the following five responsibilities:

(1) Job knowledge.
(2) Knowledge of company policies, rules and the agreement existing between the company and union.
(3) The ability to instruct workers in manual jobs.
(4) The ability to plan, schedule and develop better methods.
(5) The ability to maintain good management-employee relations.

10. Training can provide women with job knowledge adequate to the responsibility of foremanship. While it is not traditional practice to recruit women for apprenticeship, it must be remembered that a good many of our male supervisors also have not served apprenticeships, and are selected because of characteristics other than the qualification of being the best mechanic in the shop.

11. Imparting information on company policies, rules and safety practices,

and interpreting the terms of the union agreement can be done equally well for and by women as by men. This has been clearly demonstrated in such companies as use large numbers of women supervisors, not necessarily foundries, as this qualification is a basic one, equally applicable to foremen on any job regardless of the type of industry. In times when organized labor is the source of many of the management problems, maintenance of good job relations is of foremost importance.

Instruction Ability

12. The ability to instruct workers can be developed very easily through the use of "Job Instructor Training" (J.I.T.), and it has been our personal observation that very often a woman in the group has done the outstanding job of training and has proved to be the best member of the class. The fact that many women have not had previous industrial experience has made it necessary for them to break down the jobs carefully, listing the principal steps and picking out the key points. This is a key to successful job instruction.

Job Housekeeping

13. Their natural aptitude as good housekeepers tends to make them superior in having everything ready and the work place properly arranged. They are inclined to take more care in preparing the workers and putting them at ease on a new job. Patience is an attribute natural to women, and they present the operation to the learner carefully and patiently, taking up one point at a time.

14. In trying out the performance on the job, they correct errors with a minimum of friction. Follow up comes natural to any woman who has run a household and made sure that Johnny has combed his hair and put on his tie, that Mary has taken her lunch to school and that Dad wears his galoshes. Let us ask ourselves: "Who has done the training job with the children, from the cradle until maturity?" Let us capitalize this experience to industry's benefit.

Planning and Scheduling

15. The art of planning and scheduling work is another matter in which women have a natural aptitude, and what they lack in mechanical knowledge, in order to make job improvements and the simplifying of working procedures, is more than made up by insisting on an orderly procedure and meeting production schedules.

16. No one would deny that some women can develop superior abilities in the field of job methods, and we all have paid our respect to the work of Lillian Gailbraith. The "Job Methods Training Program" of the "Training Within Industry" is admirably suited for developing, to an extensive degree,

this phase of the foreman's job, and women have made some outstanding contributions in the improvement of job methods following this training program.

Human Relations

17. Again, the natural aptitude and long experience that women have had with maintaining smooth relations in running the home have aquipped them with the four basic steps in handling difficult situations and human relations problems. Getting the facts, weighing and deciding what to do, taking action and checking results are the fundamental procedures in dealing with employee relations.

18. The "Job Relations Training Program" (J.R.T.) provides the necessary training for anyone to deal with the many problems of handling people on the job. Again, women have clearly demonstrated their ability to assimilate and put into practice the knowledge gained from this program to the same degree, and we might go so far as to say a greater degree, than many male supervisors.

SUPERVISORY SELECTION

19. Selection of individuals for supervisory responsibility is a major problem. Too often, insufficient attention is given to this phase of securing proper supervision. The plan we would suggest is a very simple one. Ask yourself if you have any women in a department who, *if properly trained*, would make good supervisors. It is assumed that the requirements of the specific foreman's job have been clearly defined. If this has been done, the candidate's qualifications can be weighed against the requirements. Getting information about and from the individual candidates is fundamental.

Aptitude Testing

20. Testing can be used if deemed desirable or necessary, and the usual battery of tests can be applied equally well to women as to men. Further, women with previous supervisory experience in other lines of work can be hired directly from the outside. Women supervisors from book binderies, clothing manufacturing plants and light mechanical assemblies have been employed as supervisors in heavy industry with a very marked degree of success.

Training

21. No management would expect to select a man from the ranks and vest in him the authority of a foreman without providing training in the techniques which are peculiar to management's responsibility. The same procedure should be followed when and if women are used as supervisors. The training should be exactly the same, only more so. By way of explana-

tion of the "more so," we would like to remind management of foundries that too often training for supervisory responsibility is left to training by absorption rather than by intention. While the school of hard knocks and experience is a good teacher, it is equally true that many simple and fundamental truths are learned at a very high cost in lost production, sit-downs, strikes and frequent grievance meetings.

22. If we remember that a foreman does not run a coreroom, cleaning or molding department, but that his main responsibility is to handle people who in turn get out the production, keep down the costs and stay on the job, we can find no good reason for not using women as supervisors in a foundry as well as machine shops, assembly plants, optical goods manufacturers, textile garment manufacturers and the many other fields in which women have acted as foreladies for many decades.

Summary

23. In summarizing the entire problem of using women as supervisors in foundries, we must be ready to admit that it is more logical to employ them as supervisors than as production workers. We must further recognize the contribution they have made as supervisors in many other fields of endeavor, and ask ourselves why the foundry industry can not meet the challenge in this single activity as it has met the progressive tactics of other industries in every other phase of the management problem.

24. For the sake of remaining practical, I would like to say that, in my opinion, the use of women as supervisors in foundries and other heavy industries is expedient only as a war time measure, for it is recognized that the turnover in normal times would make the practice of using women as supervisors an uneconomical procedure.

A Postwar Foreman

By T. H. Booth*, Washington Park, Ill.

Introduction

1. To look into the immediate future and extend presently known trends and principles concerning foremanship seems very timely. When the American Foundrymen's Association requested a paper prepared on the subject of the "Postwar Foreman," we inquired how much our company and our foremen had thought and planned for future conditions. Such planning is important not only in the view or prediction of what may happen, but because corporately and individually we can help to make events through proper preparation, courage and energy.

2. Postwar conditions are a challenge, particularly a challenge to industry. The public esteem of American industrial leadership has risen and fallen and risen again. The great "Captains of Industry" era of 50 years ago was followed by a long period of regulation resulting from a public demand for protection of the rights of the small man.

3. The climax of this period probably came in the depression 10 years ago, when the reputation of "business" as such and anyone connected with it reached bottom. So far in this war, industry has made a remarkable record and grown considerably in public esteem. This change benefits both the companies for which we work and us equally through our satisfaction in our work.

Changes in Foremanship

4. Thinking of these general industry changes leads us to inquire what changes have taken place in foremanship, and we think you will agree that we should take stock of the situation. It is safe to say, broadly speaking, that at the turn of the century a foreman usually was pretty much of a king. He performed all functions; hiring, firing, setting wages, specifying equipment and often building it, determining methods, altering designs to suit his shop and, in fact, doing everything that the big boss and the bookkeeper did not do. Probably some of you remember that this is no exaggeration.

5. Plant foremanship was a highly respected position in the eyes of the community. However, at the same time industry became regulated it was becoming more and more complex and functionalized, making the foreman more highly specialized and less conspicuous.

6. The attractions of clerical or white-collar jobs drew more and more persuasively, while the need for education and technical training for fore-

*Works Mgr., Walworth Co.
Note: This paper was presented at a Foreman Training Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 25, 1944.

manship increased, thus limiting the numbers of first-class foremen while the demand grew larger, until it became apparent to some industrial leaders that a whole new program was needed.

Training Development

7. Then special training for manufacturing executive work spread rapidly, and more of the capable young men were induced to stay in the factory rather than migrate to selling and office jobs. I do not need to tell you of this change of custom, which you have seen, but it is important to take a bird's-eye view of the course which we have been following in order to be sure of our direction in stepping off into the future.

Need of Trained Foremen

8. Now for the years after the war. If we can read any sign in the events of recent years, it surely must point to a need for much more highly trained and more responsible foremen. The enormous developments of the past 3 years in technical improvements in processes, materials and methods are bound to upset many a competitive balance.

9. Some plants will go ahead and some will lag behind. The amount of money invested in new plants will upset many an established situation, which will call for a new lowering of costs to meet competition of others in the same line of work, and competition of others with substitute materials invading a prewar market field. The competition of a new foundry with the latest sandhandling, melting, molding and cleaning equipment can be met, but only met by clear-headed, highly efficient operation of an old foundry.

10. For instance, if a certain casting is made by centrifugal casting at a new low cost, you may not have to go to centrifugal casting—there are many ways to skin a cat—but you certainly will have to re-examine your whole process to eliminate cost or give up the market which was yours before the war.

11. The much talked of plastics may not seriously invade the metal castings field, but they certainly will force we foundrymen to do some tall hustling to retain markets. All of this means an insistent demand on the foreman for broader technical knowledge and application of it in his everyday operations to produce better quality and lower cost.

12. New tools are in our hands for control of melting and control of sand condition. We may have all the laboratories and technicians we want, but they are only assistants to the foreman, who must understand them and know how to use them to get results. The postwar foreman must be an engineer.

PERSONNEL ADMINISTRATION

13. However great the technical demands look, the requirement in personnel administration looks even more important. While the foundry became more complicated and technical, we have had a revolution in the relations

of management and labor. There has been a tendency to concentrate the handling of these relations in personnel officers, but the foreman must be the first and continuous contact. The boss is the workman's daily contact with management. He looks to him for leadership, and a specialist from the front office is not a good substitute for a man who can say yes and no right on the job.

14. We have no doubt that collective bargaining is going to increase, rather than decrease. The same thing holds true of that deal called collective bargaining as of any other bargain; it is a permanent bargain only if it is advantageous to both sides. Life has been pretty trying for many foremen under existing conditions because, at best, each decision concerning his men had to be correct beyond question if peace and morale were to be maintained.

Foremen as Company Representatives

15. The foreman represents his company as can no personnel officer. He must present a true picture every hour of the day, and deal out understanding justice with tact far beyond that which would suffice in years past. It is only fair that this should be so, and it is good business.

16. Of course, technical changes make training problems, although we believe anyone who has survived the current training problems will easily maintain his place during the next few years.

17. A new attention has been focused on absenteeism, labor turnover and safety measures, and it seems that the results of this attention have been so worthwhile and sound that continuing efforts should be made by the foreman to so know and handle his men that these losses will be kept low.

Wages

18. The very core of personnel problems revolve about wages, and wages can be best interpreted to the wage earner by his foreman. It is not enough simply to know what the scales and rates are. There should be a thorough understanding of how they are set and why they are sound and fair.

19. If, as seems probable, there is a postwar "Labor Board" of some sort, we will have to know more about job evaluation, man-rating, time or job standards and scientific methods development. It seems likely that all of these techniques will be used more and more in the setting of and administration of wage scales. The ability to clearly explain and sell his men on his wage scale should help the foreman.

Grievances

20. The handling of grievances is not a separate function. Fair, just and prompt handling of workers' complaints or problems is part and parcel of the everyday work, and will be just as important even though there is a

buyer's labor market instead of the present seller's market, because what each one of us desires is a thoroughly sold and cooperative workman.

21. An employee who respects and likes the management for which he works is the best advertisement for continuing the American system of free enterprise, so the postwar foreman must be first-class in his personnel administration.

Supervisory Trend

22. Now, to the advantage of the foreman, we do believe that the present trend will continue to place the foreman in a more satisfactory personal position. Perhaps too many functions were taken out of the hands of the foreman, and as individual men show that they can handle, or at least oversee broader responsibilities, they are being entrusted with them. Certainly, during this war the position of foreman seems to have grown in the eyes of the whole community as well as management.

Shop Conditions

23. As shop conditions become more and more agreeable and comfortable and hours become shorter, even though technical and personnel problems increase, we will see more men stay in the shop and more thoroughly trained men go into the shop than ever before. The economic position of the shop versus the office and the sales field has changed in the past few years. Perhaps, leaving behind us the era of minimum production, we are headed for an era of maximum production.

24. So, if we are to produce it would be sensible for the forward-looking foreman to know as much about the general aspects of management as possible. To name a few; how much the product costs, what the variable costs are and how they may be controlled, where the money that finances the company comes from and where it goes, to whom the product is sold and how it is used, why it is a good product and how it may be made more useful. An informed understanding of the problems of the enterprise make for a more effective execution of the department, no matter how large or how small.

Conclusion

25. We recall that in speculating on the needs of the future we have brought up a picture of a perfect paragon of a man. That is what industry needs. It is worth while trying for, corporately through a well-organized program, and individually through grasping every opportunity for advancement of knowledge and daily concentration on improvement in results. After the war we must deliver the goods, more goods delivered to more people earning more wages than ever before.

26. If the American way of competitive free enterprise is to go on, industry must do it to the satisfaction of the public. It requires preparation, courage and energy. No one will play a more vital part than the foreman.

Training Foremen Through the Conference Method

By Steven G. Garry*, Peoria, Ill.

Introduction

1. Webster defines "conference" as, "the act of consulting together formally; an appointed meeting for discussing some topic or business." As in all definitions, this can be broadened out considerably, but the essence is there. May we say further, that the conference is a means of promoting and developing practical men to *think for themselves.*

2. The purpose of the foreman conference is not designed to provide the educational principles of demonstrations, lectures, classes, or bulletins in giving information to supervisors. Rather, it is a designed purpose to fulfill a need which none of these meet—the *active* employment of the thinking process.

What Is the Conference Method?

3. In a figurative conference, a group of supervisors (15 to 20) sit informally together to interchange their individual experiences, points of view, and to gather together their various opinions, with the object in mind of arriving at some definite conclusions. You will notice that the word, informally, is used which is contrary to Webster's use of the word "formal." It has been found, naturally, that the use of informality gets the best results.

4. Each conference has its leader, whose purpose is to open the discussion by stating a problem, or problems, clearly and seeing that each participant has an opportunity to express himself, keeping all discussions to the point and summarizing the conclusions involved.

Time of Holding Conferences and How to Group Participants

5. In industry, if there is the least need of management compulsion, the conference should be held on company time. If the conference is offered as a strictly optional opportunity, then the evening conference, on the men's own time, is apt to be the best, for we all appreciate what we make an effort to attain, rather than what is placed too easily within our reach.

6. If conference training is properly sold, compulsory attendance need not be necessary. Curiosity first will attract the foremen, and later, because they find the time has been well spent, they will be eager for the next problem to be discussed. There will always be some foremen who are certain that their experience as supervisors has taught them more than they can learn

*Supt. of Coreroom, Caterpillar Tractor Co.

Note: This paper was presented at a Foreman Training Session of the 48th Annual Meeting, American Foundrymen's Association, Buffalo, N. Y., April 25, 1944.

from younger minds. They think that foremanship cannot be improved. Then, it is often necessary to urge their attendance, if for no other reason than for the benefit of the rest of the group.

Scheduling Conference Hours

7. The scheduling of conference hours is best determined by the men themselves. A simple method is to obtain from them, individually, the hours during the day when they feel they could not possibly be absent from their working department or force. It is also advisable to ask them to state any days of the week, or dates which they would prefer to avoid. From such information, a satisfactory schedule can be easily made. If conferences are to be held once each month, each group should be scheduled for a certain hour, place, day and week of the month, and that schedule followed throughout the program, rather than make the meetings subject to call. Advance notices may serve as reminders.

Conference Grouping

8. Now the question arises. Who shall attend these conferences and how shall the foremen be grouped?

9. There are several factors governing the answer, and these are:

(1) The extent and scope of the program.
(2) The number of persons available as conference leaders.
(3) The general nature of the organization. Management may pick certain representative foremen, or supervisors in each department or division, and recommend them as members of a group. This selection is justifiable if there is a scarcity of conference leaders. A careful selection of open-minded, trainable men will do much toward instilling in others a desire to attend similar conferences.

10. The most economical program is to include all foremen, from the top supervisor to the sub-foreman. Thus, no favoritism or jealousy will be encouraged and good feelings will be spread throughout. This all-over program puts new dignity upon the job of foreman, and at the same time makes for greater democracy between the various levels of supervisors.

11. It has been found that a mixed group produces livelier discussions, with more angles of approach, than a group associated closely together in their work whose thinking has been steered along similar paths for years. Then, too, more experienced foremen can share and contribute their mature knowledge to less experienced supervisors. In this way comes the development of a philosophy for handling men and problems which would come out of the individual experience of each foreman, and yet be a vast improvement upon the ideas and practices of most.

12. There is one point on which we all can agree about the training of foremen through the conference method. The requirements and conditions will vary in almost every plant. We must consider that some plants have grown and expanded many times without having available men well qualified for supervisory positions. Thus, it is easy to see why conference training must differ between one plant and another. In fact, training conferences may even differ within one company if the organization should operate several branches.

Elective Conference Method

13. It is because of these circumstances that we have found that the best results can be obtained through the "tailor-made" or elective conference method, one which is shaped to fit the needs of any group of supervisors and organizations.

14. Several years ago, we began our foremen conference program by using "purchased finished" material. Upon completion of this training program, we prepared our own material, designed to solve the general problems existing in our organization.

15. All of the conferences were handled by plant leaders and supervisors in typical conference style, with the objective of stimulating thought among each group and developing supervisory ability. A wide range of subject matter was selected, including waste prevention, good housekeeping, safety, cooperation, instruction, good workmanship, reclamation, employee records and other general topics.

16. After continuing this program for some time, the War Manpower Commission made available the "Job Instruction Training" course. Every supervisor received this course. This training was very well received with enthusiastic comments. From this program sprang the plans for the present courses offered to all supervision. Short courses on several subjects were included in the training program. The selection of a course was left entirely up to the foreman himself. He was allowed to select the course that supplied what he wanted or needed. Thus the name "cafeteria style" came about.

17. The plan is entirely voluntary, and it has been found that the foreman usually will determine his needs rather precisely. In this way, dull meetings are overcome and a definite interest is maintained. Two types of subject matter are used; one dealing with processing methods and the other with the personnel side of supervision.

18. The foreman was approached with a folder which emphasized "no textbooks—no examination—elective." He was *invited* to choose the subject, or subjects which would interest him, help him in his work, or make his duties easier. If nothing appealed to him, it was suggested that he make no choice, because it was more important for him to be at his regular job than to attend conferences that were not interesting to him. Meetings were

to be held semi-monthly, and only one course could be taken at a time. It was further stated that whenever ten supervisors on the same shift chose a subject, a meeting would be scheduled immediately.

19. On the enrollment card, the applicant was allowed four choices, and also was asked to suggest subjects not included in the course. The subjects offered at present are: Accident Control, Accounting, Time Study, Metal Processing, Heat Treatment, Products at Work, Supervisor Routine, Quality Control, Job Instructor Training, Job Methods Training, Job Relations Training, Effective Speech, Legislation, Economics of Industry and Elements in Supervision.

20. The following description for one of the conferences is typical of those given in the folder:

> "*Job Relations Training* provides helpful ideas for getting along with people. Important points and considerations are developed by the case system of study. These cases are standard circumstances from which the best solution is developed. Stresses important characteristics and traits. Recommended for new supervision. (Five semi-monthly meetings.)"

21. The response to the offering was excellent. In fact, it was more favorable than expected. Seven out of ten foremen registered for an average of 3.6 subjects.

22. Plant leaders for nine of the courses were provided from the personnel of the training department. Others were provided from the plant, or general office. The method of the conference naturally varied with the subject, but the straight conference method is used wherever possible, but in some courses the combination lecture and discussion method is followed.

23. All conferences are held on company time and require careful scheduling so that only a reasonable number of supervisors from any one part of the shop are absent from their duties at one time.

24. It has been gratifying to note that the program is developing self-confidence among foremen. They are finding that the subjects selected are helpful in one or more of the following ways:

(1) To intensify their technical understanding of the job.
(2) To provide material for developing better job relations.
(3) To provide morale-building information.
(4) To get a slant on the other fellow's problems.

The Group Number

25. The group itself should contain not less than six and not more than 20 persons. Less than six persons has a noticeable awkwardness about it, and, too, the quality of knowledge, ideas and experiences will be diametrically adjusted to the number of persons conferring. On the other hand, if the

group exceeds 20 persons, there is great difficulty in securing a contribution from everyone. It is extremely important that all participants must talk, or have an opportunity to do so.

THE SUBJECT MATTER

26. Since the conference is a means of gathering unrelated bits of knowledge picked from the minds of several different people, there can be no conference on a matter of fact, or on a question which can be answered "yes" or "no." There must be an organized discussion, argument, debate, or explanation. To uncover dormant thoughts and bring out opposing points of view, the conference must use the motivating principles, or challenge of argument. Thus, the subject must present a problem, a felt difficulty, or a controversial subject.

MANAGEMENT COOPERATION

27. No foreman conference can succeed without the whole-hearted support and cooperation of the management. Management must be eager to receive the opinions of his foremen as formulated, and to put into practice whatever changes or suggestions seem wise. Nothing could defeat a conference program more than a disinterested management group.

28. One means of holding management interest in the conference is to form a conference group of the executive force to meet and discuss the same subjects which are presented to the foreman group as a whole. Thus, management becomes familiar with the questions and problems which are being discussed, and can compare the foreman's reactions with their own. Company policies can be more readily defined and formulated and make for consistency in their application.

29. If the supervisory force is aware that management is discussing the same subjects, they will be more free with their opinions and in their expressions. Without management's participation, we run the risk of developing other policies among the rank and fiie of foremen than management, busy with finance, organization and other matters, will be able to appreciate.

30. On the other hand, the program sponsored and endorsed by the management can not be shoved down the throats of the foremen. The initial introduction of the idea should be so presented that the foremen will feel that here at last is an opportunity to exchange ideas and to express some of the difficulties which have been confronting them.

BENEFITS AND RESULTS OF CONFERENCE TRAINING

31. We have stressed the importance of discussion and exchange of ideas during the foremen conference, and the guiding by the leader of the discussion toward a broader and more human philosophy of handling men. If the conference does nothing more than open new methods of approach and question old habits, it has already accomplished something. But that is not enough. In

order that the time and effort spent on the conference program may be worth while, it is necessary to be sure that the conference members are going to "do something" about whatever situation they have been discussing.

32. The introduction of the conference method in industry has a distinctly democratizing effect. The conference has assisted in "The Partnership of Interest" which has been the goal of all those concerned with industrial relations, now that the employees themselves, by means of conferences, lay down many rules governing their own conduct.

Purposes of Conference Training Method

33. There are five separate purposes for which the conference method may be used in industry.

(1) To develop job-hunting methods.
(2) To work out accident prevention methods.
(3) To solve problems in supervision of men and work.
(4) To develop a practical philosophy of handling men.
(5) To develop customer-contact technique.

34. The modern foreman has a need for all the assistance he can obtain. Under today's conditions, the duties of the foreman are many, and he is expected to have vision and a knowledge of industrial technology of a far greater extent than ever before.

35. The value of the conference is the simple, practical treatment of each of the problems of foremanship. It should also serve as a school or training center for all attending.

36. Now, let us see what the problems are for fundamental efficiency of good foremanship, and how this training can come through the conference method.

First, for efficient management, the foreman must investigate, find out his problems, compare them with others, and discuss solutions. What better means can be found than by grouping other department foremen together for their viewpoints, questions for solution and comparisons?

Second, to attain uniform interpretation of company policies.

Third, to make plans.

Fourth, to achieve standards.

37. As has been stated before, the responsibilities of a foreman in industry today have multiplied. Much of this is due to general industrial advancements and improvements.

38. Both the foreman and management realize the need, first, of quickly issuing to foremen information about matters affecting the performance of their

duties, and, second, that the information must be in a clear, concise form which will permit a ready understanding of the facts involved with as little chance as possible of variations in interpretations.

CONCLUSION

39. It is said that in certain Oriental countries physicians are paid so long as they keep a patient physically fit—and their pay stops when the patient becomes ill. Conferences, like the Oriental medical men, are not primarily intended as a means of correcting some supervisory ailment we may have contracted, but rather, should function to help keep us as foremen "on top of our jobs" at all times.